# Cultural Globalization

## Embodying Cultural Identity Through Emerging Digital Tectonics

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School of Architecture
University of Hawai'I at Manoa

**Doctorate Project Committee**
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*We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in partial fulfillment for the degree of Doctor of Architecture in the School of Architecture, University of Hawai'i at Mānoa.*

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## Abstract

This research focuses on the reinterpretation of Gayageum, a traditional Korean string instrument as it relates to traditional and contemporary digital design technology (e.g.: CAD/CAM). I chose Gayageum as the existing cultural symbol to focus my research on because its structural system contains elements similar to those of architecture. My hypothesis is as follows:

> Regardless of the complexity of the initial ‘design’ phase of Gayageum, by reducing the complexity of the Gayageum’s assembly and construction, its form, function, structure and other essential functions can be reinterpreted as a new cultural symbol organized with digital assembly logistics in relation to a specific interpretation of everyday life (i.e.: eastern Taoism) and digital tectonics, then the meaning of humans’ every day existence can be found in digital tectonics as related to the design-build of local architecture, which embodies cultural identity.

I propose a possibility that merges disappearing local cultures and emerging digital cultures together through my hypothesis.

The goal of my design-build experiment is to create a new cultural symbol by reinterpreting existing symbols using a digital assembly logistics to incorporate design, culture, tradition, and contemporary architecture. It is a connection between traditional identity and global digital technology. I plan to incorporate a variety of designs, cultures, traditions, and contemporary architectures by using digital assembly logistics. As a design methodology, I reinterpret Korean

lifestyle including Korean paintings, Korean rice paper and even Korean sport, to guide the development of a form-finding process.

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# 1. Introduction and Historical Review: Design and Culture

In this chapter I argue why the reinterpretation of gayageum is meaningful. Then, I research the meaning of design that drives my doctoral design project. The design project is to design and fabricate a new instrument using a digital tectonic that is inspired by the Korean traditional string instrument, gayageum. It is critical to understand the cultural relationship between the design of the instrument and typical, everyday life since Korean traditional instruments are a critical component of Korean culture and life. Based on the interpreted design, I set up a hypothesis of my design project that incorporates gayageum, design, and contemporary architecture.

## 1.1 Reinterpretation of Gayageum

The reinterpretation of gayageum, a traditional Korean string instrument, is theoretically meaningful. Some argue that the contemporary society based on the digital manufacturing culture, such as mass production and customization, threatens the traditional identity of handcraft. However, I believe that the recreation of tradition using digital technology, such as the reinterpretation of gayaguem in this study, can contribute to the development of a positive harmony between the digital manufacturing culture and traditional handmade culture.

Nam June Paik, who founded video art, focused her artistic efforts on the portrayal of the humanization of technology by using video art as his medium. The “TV Bra for Living” Sculpture, created by Nam June Paik and Charlotte Moorman in 1969, for example, represented a brassiere of wearable televisions. The images on these television screens changed accordingly with Moorman’s cello playing. Paik argued that a brassiere, a most woman’s most intimate possession mixed with the technology of a television exemplified the humanization of technology. Paik intended to stimulate spectators’ imaginations, encouraging them to consider how technology can be humanized. [1]

Figure 1.1 TV Bra for Living

My design project shares this objective of humanizing technology with Nam June Paik’s video art by reinterpreting the gayageum as a symbol of the localization

1 Min Su Kim, A Room for Culture, A Room for Design (Seoul: Greenbee, 2009), 127-129.

of global digital technologies. The fundamental goal is to encourage my audiences to consider and embrace the localization of digital technologies.

Le Corbusier, one of the most influential architects since 20th century, explained the significance of the "tool" is its contribution to contemporary architecture by merging digital techniques and manufacturing tools. Today's lifestyle is anchored with mass production and customization intended to reduce a significant fraction of cost and construction time. While commodities like mass production and customization may act as a source of comfort and increase efficiency of contemporary lifestyles, local identity, which is represented by historical traditions, conflicts with these commodities, which is a demonstration of an emerging conflict between globalization and traditional culture and lifestyles. Traditions such as that of handcrafting objects has been seriously threatened by emerging digital culture. However, such tradition can be sustained by reinterpreting cultural contents using the digital design technology of the digital age.

In architecture, it is essential not only to know the tectonics of assembly, but also to lucidly represent the assembly process to fabricators. In the current digital age, architects can draw forms easily and change the parametric data by using computing power such as various 3D drafting software allowing architects a newfound freedom of design. However, their freedom is limited by their ability to provide clear manufacturing instructions to fabricators as assembly methods have yet to catch up to the vast modernizations of design techniques. In most cases, three-dimensional structures are composed of two-dimensional materials, so the understanding and the representation of assembly logistics are Abcritical to the design-build process. This assembly logistics is to the reinterpretation of gayageum in this study.

### 1.2 The Origin of Design and its Meaning

According to the Oxford English Dictionary, the definition of design has the following two etymological origins: The first origin is the Latin *desegno*, which means plan, purpose, intent, model, and picture. This term was established around the same time as the French word *desseing* in the fifteenth century. The meaning of *desegno,* which meant a preliminary sketch or a drawing in a painting, has evolved to mean creative thinking in the mind of an artist. The meaning of the word design, which originated from *desegno* and *desseing,* was initially defined as the plan of mind. Therefore, the modern conception of design lexically means an intended plan recognized in the mind that is subsequently executed. The word design, however, has various meanings according to the purpose of the activities, making the concept of design ambiguous more often than not. The design adopted for engineering purposes, for example, means only mechanical design. The design adopted for management purposes means a plan for the rationalization of management. The design adopted for artistic purposes only means the pre-conception of the artwork.[2]

The second origin of the definition of design is the Latin *designare*, which has become a very rarely used term. *Designare* means to indicate or signify, and its

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2 Min Su Kim, "Cultural Meaning and the Role of Design," http://blog.daum.net/pgfive/15493795 (accessed October 29, 2012)

etymological structures are composed of *de* and *signare*. The prefix *de*- means "to separate or to take away," and *signare* means a sign or symbol. When *de* and *signare* are combined to create the whole word *designare*, it means "to act to create a new symbol separated from the existing symbols."[3] In short, the meaning of the design from the Latin word *designare* is "to interpret symbols that already exist to create a new symbol." These implications offer critical etymological clues that help explain the relationship between design and culture. The definition of design in my doctoral design project is based on the second origin of design, defined as "the creation of new cultural symbols by interpreting existing symbols."

All artifacts, including objects and images created by humans, correspond to a conventional symbol. Artifacts can be defined as an arbitrary set depending on the human's conscious needs and interests. When the concept of design and tools are understood in these ways, it can be argued that design and tools are a means of life. All archaeological and anthropological records prove that humans have expressed their way of life through artifacts and images since the beginning of civilization, which is why many archaeologists and anthropologists argue that artifacts and images are not only the means of life, but also a concentrated expression of thinking. In a sense, the tools have the same function of performance as a language. As it were, we create our activity and culture through artifacts and images as we communicate through languages. The appearance of a new chair suggests, "this is for seating" as opposed to other seating symbols. The design of a certain artifact not only means to create something considering function or

[3] The Compact Edition of the Oxford English Dictionary, volume I. A-O (London: Oxford University Press, 1971), 243.

aesthetics, but also implies a promise of the way of life by suggesting “let’s live this way.” Therefore, the design is instantly dependent on cultural influence regardless of how it is produced (by hand or by machine) or how it looks (graphic, architecture, interior, city, or clothes). On November 29th, 1994, for example, Korean people installed a time capsule in the Korean village of Namsan. It was an event to celebrate and commemorate the 600th anniversary of the founding of Seoul as the nation's capital by putting into the capsule 600 items that represent contemporary life and the city, so that 400 years from now, i.e., on the 1000th anniversary, our current life can be handed down to our descendants. The time capsule contains everyday items such as tableware, daily newspapers, money, credit cards, IDs, small electronics, subway tickets, and pantyhose, with scaled models of other items such as a computer, car, subway, excavator, and Jamsil Olympic Stadium. In addition, the contemporary life was vividly recorded into various video records through compact discs and laser discs. Descendants will read a culture of our past through the time capsule. If we clearly understand the purpose of the installation of the time capsule, it will be easier to understand the significance of design that contains critical meaning beyond simple industrial meanings. The fundamental role of design is to create and record a culture by containing and regulating our everyday life. Therefore, I define culture in my doctoral design project not only as a process of thinking and activities that construct our lives, but also as an artificial environment which is generated by interpersonal. Based on the concept of culture, my doctoral design project is communicating the way of life as "the analysis and the creation of new cultural symbols by interpreting existing symbols."[4]

### 1.3 Design and Life

If the act of designing considered is an activity involved in the interpretation and creation of a cultural symbol, it should be understood that design is equivalent to the phenomena of everyday life. The everyday reality people experience could be compared to a constantly changing flow.

Many dysfunctional designs are derived from the misunderstanding of everyday life. Modern high-rise apartments in Korea, for example, are compromised by the design that considers everyday life a typology of functional parameters, which disregards casual behaviors. Everything from the cities' transportation network to common recreational activities are analyzed and classified as a typology of controlled parameters and therefore do not accommodate basic functions of common behaviors. Over time, residents of these said modern towns complain about the lack of functionality. Through people have learned to adopt within their environments, some still seek to design living spaces that rectify their complaints. Some people, for example, break structural walls to change their living space in their apartments although it is strongly prohibited by law, and others change the curtains or wallpapers. Cars are an example of how people adjust to various design objects. Things such as

[4] Min Su Kim, "Cultural Meaning and the Role of Design."

modified aluminum wheels, widened tires, gold foil trash cans, wool car-seat covers, and stickers that say “Racing Bomb” or “Transformers” are demonstrations of life conflicting with uniform objects. Designers typically design their products based on measured and typological analysis from market research rather than actual sense of everyday life. However, these measurement parameters prevent car designers from being able to accommodate mundane life demands or individualized preferences. Thus, it is critical to express everyday life not only measurably and concretely, but intuitively and symbolically as well will continue to reflect the common understanding of everyday life. Otherwise, people will continue to manipulate in the objects design by personal means.[5]

Culture has been generated by everyday life, and life is composed of people’s behavior. Thus, human behavior is a critical component of cultural understanding. Reactions to objects and the objects that influence human behavior are all essential elements to understanding the relationship between design and everyday life.

### 1.4 Hypothesis and Goal of Design Project

In my design-build project, I focused on gayageum, a traditional Korean string instrument, as a model of an existing cultural symbol, which shares certain functions with architecture. The traditional string instrument demonstrates remarkable balance between its body structure, form, and function by enduring tensional and compressional stress. The Ukulele, for example, has a body that

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[5] Min Su Kim, “Cultural Meaning and the Role of Design.”

contains a void inside. The ukulele’s body is supported by hidden structures inside of it. This structural concept is exactly the same with architecture in that architecture is comprised of internal and external components that enclose a space. This enclosed space is the most functional area for both the ukulele and architectural structures, and, much like architecture, string instruments have evolved into cultural symbols based on various cultural environments.

The goal of my design project is to create a new cultural symbol by interpreting existing symbols using digital assembly logistics to incorporate design, culture, tradition, and contemporary architecture. It is a connection between traditional identity and global digital technology. For a design methodology, I make a design-build experiment of the reinterpretation of gayageum by making full-scale instrument using emerging digital tectonic by reflecting traditional Korean identity and lifestyle. I propose a hypothesis in the design project. The hypothesis is as follows: “Regardless of the complexity of the initial ‘design’ phase of gayageum, by reducing the complexity of the gayageum’s assembly and construction, its form, function, structure and other essential functions can be reinterpreted as a new cultural symbol organized with digital assembly logistics in relation to a specific interpretation of everyday life (i.e.: eastern Taoism) and digital tectonics, then the meaning of humans’ every day existence can be found in digital tectonics as related to the design-build of local architecture, which embodies cultural identity.” The hypothesis proves how my design of new string instrument contributes to contemporary architecture.

## 1.5 Research Overview

This research is composed of six different chapters: Design and Culture (chapter 1), Traditional Gayageum (chapter 2), Modified Gayageum (chapter 3), Digital Design and Fabrication (chapter 4), Case Studies (chapter 5), and Reinterpretation of Gayageum (chapter 6).

The first chapter defines the meaning of "design" and "culture" for my design-build experiment, and introduces a hypothesis and elaborates on the experiment's goal.

The second chapter examines traditional gayageum's history, manufacturing process, and structure based on the musical history of Korea. There are two types of traditional gayageum. The original gayageum, which is called Chongak Gayageum, was invented in the s century. Sanjo Gayageum is a modified traditional gayageum that played Sanjo music as early as the late nineteenth century. The emergence of folk music alongside the birth of Sanjo music and Sanjo Gayageum is a focal point of my research as Sanjo Gayageum is considered a traditional gayageum despite being a modified gayageum.

The third chapter explores the evolution of modified gayageums by researching their background, types, and features. In this chapter, it is important not only to understand the reasons why they are modified, but also to determine their cultural influences.

The fourth chapter observes how the digital tectonics appeared and how the digital tectonics influence culture. In addition, this chapter explores contemporary digital fabrication techniques with exemplary works.

The fifth chapter focuses on case studies that created a new interpretation of tradition by analyzing history and tradition as a means to fit a modern lifestyle.

The sixth chapter is an in-depth analysis of gayageum's possibilities and constraints from which I will invent a new string instrument intended to be of practical use within the context of contemporary lifestyles.

# 2. TRADITIONAL GAYAGEUM

## 2.1 History of Gayageum

Korea is East Asian country located in between China and Japan (figure 2.1.1). Korea was under monarchical rule until 1910. Just 4yrs after Korea claimed in emancipation from Japan, Korea was divided into South and North Korea in 1949. Historically in Korea, the musical cultures, art, and popular tradition shared many similar characteristics with those in China. China especially influenced Korea's high art music including the Korean string instrument, gayageum.[6]


Figure 2.1.1 Map of Korea

This chapter, examines gayageum, a widely known artifact of Korean Culture. Particularly, which was used throughout several eras in Korea history: Silla, Unified Silla Kingdom, the Koryo Dynasty, and the Choson Dynasty. I also

6 Byong Won Lee and Yong-Shik Lee, edit, *Music of Korea* (Seoul: The national Center for Korean traditional Performing Arts, 2007), 5. `

research two types of gayageums and their emergent backgrounds and cultural influences.

*Samguk Sagi*, the oldest Korean historical document which records the name of gayageum and its origin, entails a story of the coming about of gayageum. According to this story, King Kasil of the Kaya kingdom invented a gayageum using the Chinese Zheng as a model in the sixth century, then asked the musician Ureuk to compose music to be played using the instrument. When the Kaya kingdom was taken over by the Silla Kingdom (57 BCE – 935 CE), Ureuk fled the Silla with the gayageum during the reign of King Chinheung in 540 CE-575 CE. Ureuk rearranged early gayageum music based on indigenous regional music and the gayageum finally became part of the court music of the Silla kingdom.[7] Early Silla music is characterized by the 12-string zither called gayageum, which is connected to the Chinese 16-string zither Cheng and the 13-string Japanese Koto.[8] In the United Silla kingdom (668 CE -935 CE), the music of United Silla was divided into three categories based on each kingdom's indigenous music, Hyangak (indigenous Korean music), Tangak (music of Chinese Tang Dynasty), and Palhaeak (music of Palhae). Samhyon and Samjuk are local music to play Hyangak of Unified Silla. Samhyun refers to three local string instruments including Gomungo (6-sring zither)(Figure 2.1.2), Gayageum (12-string zitter)(Figure 2.1.3), and Hyangpipa (short lute)(Figure 2.1.4) while Samjuk refers to three indigenous bamboo flutes including Taegeum (long

7 Hee-Sun Kim, Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity (Seoul: MINSOKWON Publishing Company, 2008), 30-31.

8 Lee and Lee, *Music of Korea*, 6.

transverse flute)(Figure 2.1.5), Chunggeum (middle sized bamboo flute), and Sogeum (short transverse flute).

Figure 2.1.2 Gomungo

Figure 2.1.3 Gayageum

Figure 2.1.4 Hyangpipa

Figure 2.1.5 Daegeum

Figure 2.1.6 Sogeum

Music of Unified Silla was succeeded by the Koryo dynasty (935 CE -1392 CE). Aak, the ceremonial music and dance introduced from the Song Dynasty (960 CE -1270 CE) of China, was first presented to the Koryo court in 1116 and became a key part of the court's repertoire. Musical activities of Hyangak, Tangak, and Aak were mostly rituals including shrine offerings, court ceremonies, and court entertainment. In the Koryo court, the Samhyon and Samjuk were the major, musical ensembles, demonstrating how broadly used gayageum was throughout the Koryo Dynasty. During this era gayageum, was also played among Koryo literati and entertainers.[9]

The styles of Hyangak, Tangak, and Aak were accessed to court music of the Choson dynasty (1392 CE -1910 CE). Music of Koryo was abolished or rearranged according to Neo-Confucian ideology during the Choson dynasty, in

9 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 31-32.

which, music was an essential part of rituals based on Confucian ideology with the hopes of developing an idealized society. Based on Neo-Confucian principles, influenced by China, the government of Choson was more centralized than earlier dynasties; The society was based on a strict social hierarchy that is composed of Yangban (literati, landlords, officials of the civil and military orders), Sangmin (middle class, farmers, artisans, merchants), and Chonmin (underclass). Sangmin and Chonmin were the makers and workers of the society while Yangban was the Confucian privileged class. The rigid gap among different social classes separated cultural practice into two: the Confucian and Shamanistic tradition. These divisions between classes took various musical traditions including Aak (music of ceremony), Chongak (classical chamber music performed by non-professional musicians including literati, Yangban and Sangmin class), and Minsogak (folk music rooted in Shamanistic tradition). Chongak Gayageum, which has a longer history and directly succeeds the original gayageum of King Kasil, who invented gayageum in the sixth century, is used to play Chongak. The traditional gayageum is a twelve-stringed zither-like string instrument of which there are two types, Chongak Gayageum and Sanjo Gayageum. *Akhak kwebom* (1493), an encyclopedia of Korean music in the fifteenth century, describes Chongak Gayageum's dimensions, colors, and forms (Figure 2.1.7). Chongak Gayageum is also represented in genre paintings in the eighteen century, as seen below. (Figure 2.1.8 and Figure 2.1.9).[10]

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[10] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 32-36.

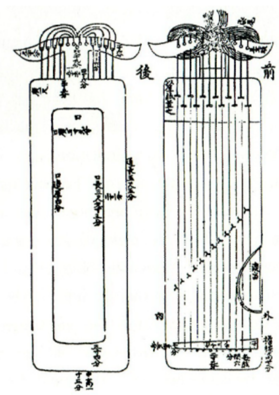

Figure 2.1.7 Drawings of Gayageum in *Akhak kwebom*, 1493, Korea

Figure 2.1.8 Chongak Gayageum in a genre painting, painted by Il-Sang Jeon, 18th century, Korea

Figure 2.1.9 Chongak Gayageum in a genre painting, painted by Yun-Bok Shin, 18-19th century, Korea

During the middle of the seventeenth century, Confucian ideology was weakened by the newly emergent ideology of Silhak. Byoung-Man Ahn writes, "Silhak was an alternative thought based on a realistic and experimental approach to social problems with greater concern for the wealth of the people."[11] Open-minded literati of practical science criticized the inequality of Neo-Confucian ideology and tried to change economic, military, administrative, social and cultural systems. The rise of this new philosophical force was a reaction to the irrationality of the Confucian ideology. Silhak also changed a culture of middle class by making middle class people's own culture that is comparable to Yangban culture. New forms of traditional music genres were created by professional musicians and artists' associations including Kagaek (literacy singers), Kisaeng (female entertainers), Kwangdae (professional musicians), Mudang (shamans), and Sadangpae (professional roaming musicians' group). They contributed to initiate new musical genres including Pansori, Kagok, Chapga, Pungmul, and Sanjo. Sanjo, which developed during the late nineteenth century, is a genre for solo instruments supplemented by a Buk (drum). Sanjo is a Sino-Korean term which means "scattered melody." Kim Chang-Jo (1865-1920) invented the Gayageum Sanjo based on Shimbanggok, a shamanistic music. In the history of gayageum music, the creation of Gayageum Sanjo is critical for many reasons. Firstly, it provides evidence of the survival of middle-class music and culture during the nineteenth century. Sanjo has more flexible musical expression than Chongak as its dynamic and lively character

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11 Byoung-Man Ahn, Elites and Political Power in South Korea (Cheltenham: Edward Elgar Publishing Limited, 2003), 24.

contributed to the personality of gayageum music. Third, Sanjo Gayageum, influenced by Gayageum Sanjo, became the symbolic traditional instrument of the twenty-first century in Korea.[12]

## 2.2 Manufacturing Process of Gayageum

The gayageum is said to contain the "sound of nature" since the gayageum is made from only natural materials. The appearance of the gayageum is a reflection of the astronomical ideology of life's definitive components melting together; the slightly curved upper side of the body represents the sky, the flat bottom side of the body is symbolic of earth, while the twelve strings symbolize the calendar's twelve months. This universal ideology is what allows many to argue that the sounds of gayageum are familiar to everyone, whether they yet know it or not. [13] The 12-string gayageum's simple melody is deep and rich, and in order to devise this sound, it is critical for manufacturers to develop a soundboard out of Paulawnia wood, a particular wood aged between thirty to sixty years old. Any older and the wood is too solid.

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[12] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 36-38.

[13] "Fly through Twelve String *Gayageum*-III," [n.d.], video clip, accessed Sep 10, 2012, YouTube, http://www.youtube.com/watch?v=mku6-Lx_MFc.

However, any younger and the wood is too soft to produce an appropriate resonance to achieve the ideal sound of Gayegeum (figure 2.2.1).[14]

Figure 2.2.1 Paulownia tree

Although there are more than ten subspecies of Paulownia in East Asia, Korean Paulownia is preferred over Japanese or Chinese Paulownia because Korea has the most ideal climate to naturally dry the wood in its rocky areas such as Sorak and Songni mountains as desired.[15] After cutting planks to 5’4” – 5’8” lengths, it is important to let them dry in the natural elements for at least three years. A craftsman monitors the weathering process to dump any planks that may rot, crack or become distorted during the drying process (figure 2.2.2).


Figure 2.2.2 Weathered at least three years

Then, the craftsman planes along the grain of the slightly convex front side using selected planks (figure 2.2.3).Although, the selected planks may all be

Figure 2.2.3 Planing

14 Keith Howard and Chaesuk Lee, Korean Kayagum Sanjo: A Traditional Instrumental Genre (Hampshire: Ashgate Publishing Limited, 2007), 21.

15 Howard and Lee, *Korean Kayagum Sanjo: A Traditional Instrumental Genre*, 21-22.

same Paulownia tree, their properties are all different, so the craftsmen must check the resonance of sound by tapping the wood's surfaces. The craftsman planes continuously until he determines the sound he is hearing has a good resonance (figure 2.2.4).

Figure 2.2.4 Adjusts planing by checking resonance

Figure 2.2.5 After planning

The appropriate thickness of the soundboard is determined based on this skillful process. Finally, the soundboard is scorched with an iron not only to prevent distortion and worm infestation, but also to deepen the grain and the color (figure 2.2.6).[16]

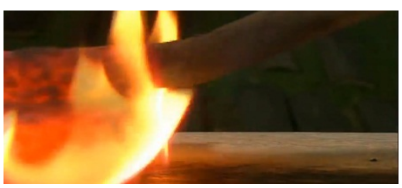

Figure 2.2.6 Scorching with an iron

Strings for the gayageum are produced from twisted silk boiled to remove starches and allow for elasticity which creates the instrument's subtle and natural sound (figure 2.2.7).[17]

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[16] "Fly through Twelve String *Gayageum*-III," [n.d.], video clip, accessed Sep 10, 2012, YouTube, http://www.youtube.com/watch?v=mku6-Lx_MFc.

[17] Howard and Lee, *Korean Kayagum Sanjo: A Traditional Instrumental Genre*, 22

The strings are then attached to small wooden pegs (tolgwae) underneath

Figure 2.2.7 Boiled twisted silk

the head of the gayageum, and passes over the fixed low bridge located at the head of the gayageum. Then, strings pass over the movable bridges (anjok), typically made from cherry wood or jujube, which delimitate the pitch (figure 2.2.8).

Figure 2.2.8 Installing movable bridges

There are twelve movable bridges referred to as “wild geese feet,” a name derived from its shape. The top of the bridges have insets cut for the placement of the string. The bridges’ slightly curved bases allow a perfect fit for the string with soundboard when the string receives compressional and tensional stress. The bridges divide the string into two sections: the right side of the bridge is the plucking area and the left side of the bridge is the area for pitch change and hand techniques to push strings. Strings, which pass over the movable bridges, are wound into coils of extra string at the opposite side of the head. These extra strings are applied to switch broken strings as necessary. The coils are connected to loops of cords (pudul), which are cotton and of blue, red, or brown color (figure 2.2.9). The cords pass through the hole in the tailpiece and are tightened to change the tension of the strings.[18]

Figure 2.2.9 Connection between coils and loops of colored cords

**2.3 Structure of Gayageum**

Chongak Gayageum is older and larger than Sanjo Gayageum. The body of the Gayageum, which functions as a sound box, is composed of a piece of Paulownia wood. The sound box's bottom side is flat with a big opening while the upper side is slightly curved. The T-shaped form of the lower end, known as the head of ram's horn (yangyidu), is a special characteristic of Chongak Gayageum. However, many Chongak Gayageum produced today are created from two pieces of wood, the flat back piece and the curved front piece, to eliminate any extraneous manufacturing costs (figure 2.2.10, 2.2.12).[19]

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18 "Fly through Twelve String *Gayageum*-III," [n.d.], video clip, accessed Sep 10, 2012, YouTube, http://www.youtube.com/watch?v=mku6-Lx_MFc.

19 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 53.

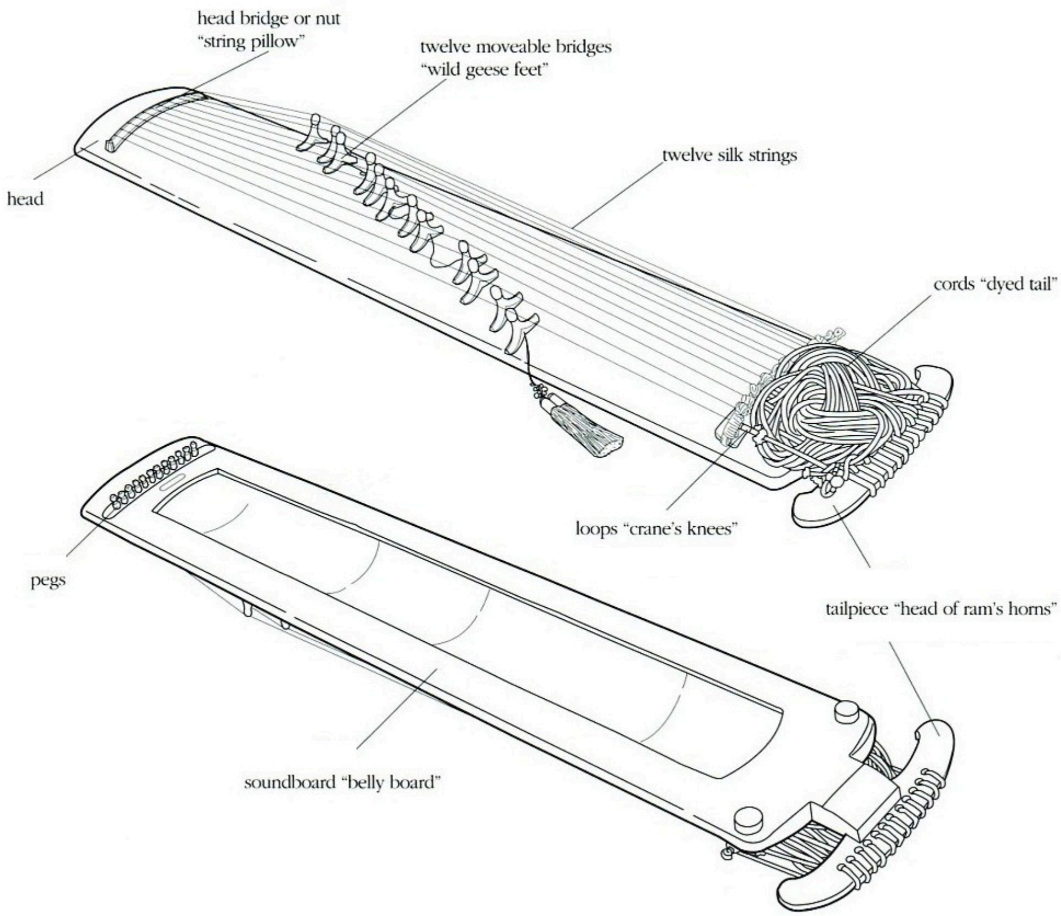


Figure 2.2.10 Chongak Gayageum

Sanjo Gayageum, which originated in the nineteenth century to play folk music, has a narrower and shorter body than Chongak Gayageum. The smaller size of the Sanjo Gayageum increases its mobility, while the shorter distance between the strings provides an opportunity for musicians to play various and speedy Gayageum Sanjo music. The soundboard is composed of two parts: the upper board, which is made of Paulownia wood in a convex shape, and the belly board which is made of flat and carved from chestnut wood. Unlike the Chongak Gayageum, there is no "head of ram's horn" (yangyidu) at the bottom. Instead, the tailpiece is simply Decemberorated and is referred to as the extreme end (pongmi). There are three holes, shaped to resemble a new moon, or, a Decemberorated oblong shape. There is also a small circle in the belly board as opposed to the large void at the back side of the Chongak Gayageum. The movable bridges and strings are smaller and thinner than the Chongak Gayageum (figure 2.2.11, 2.2.12).[20]

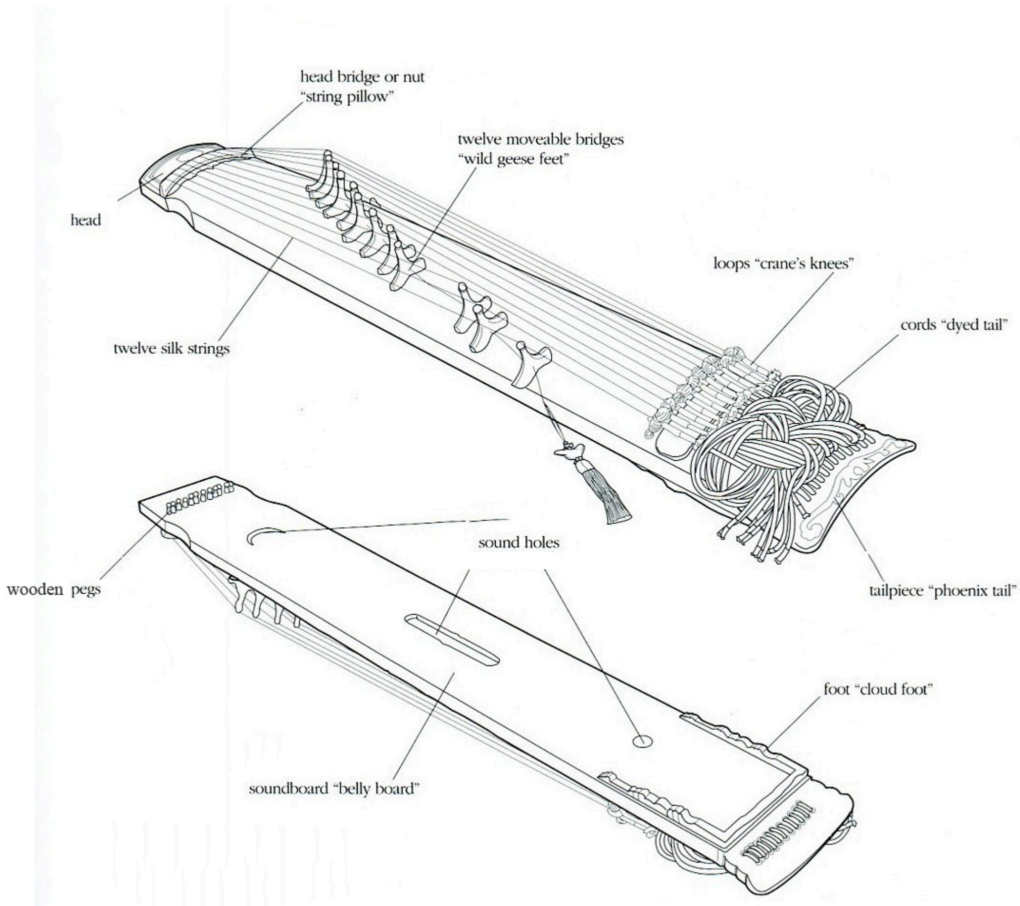


Figure 2.2.11 Sanjo Gayageum

20 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 54.

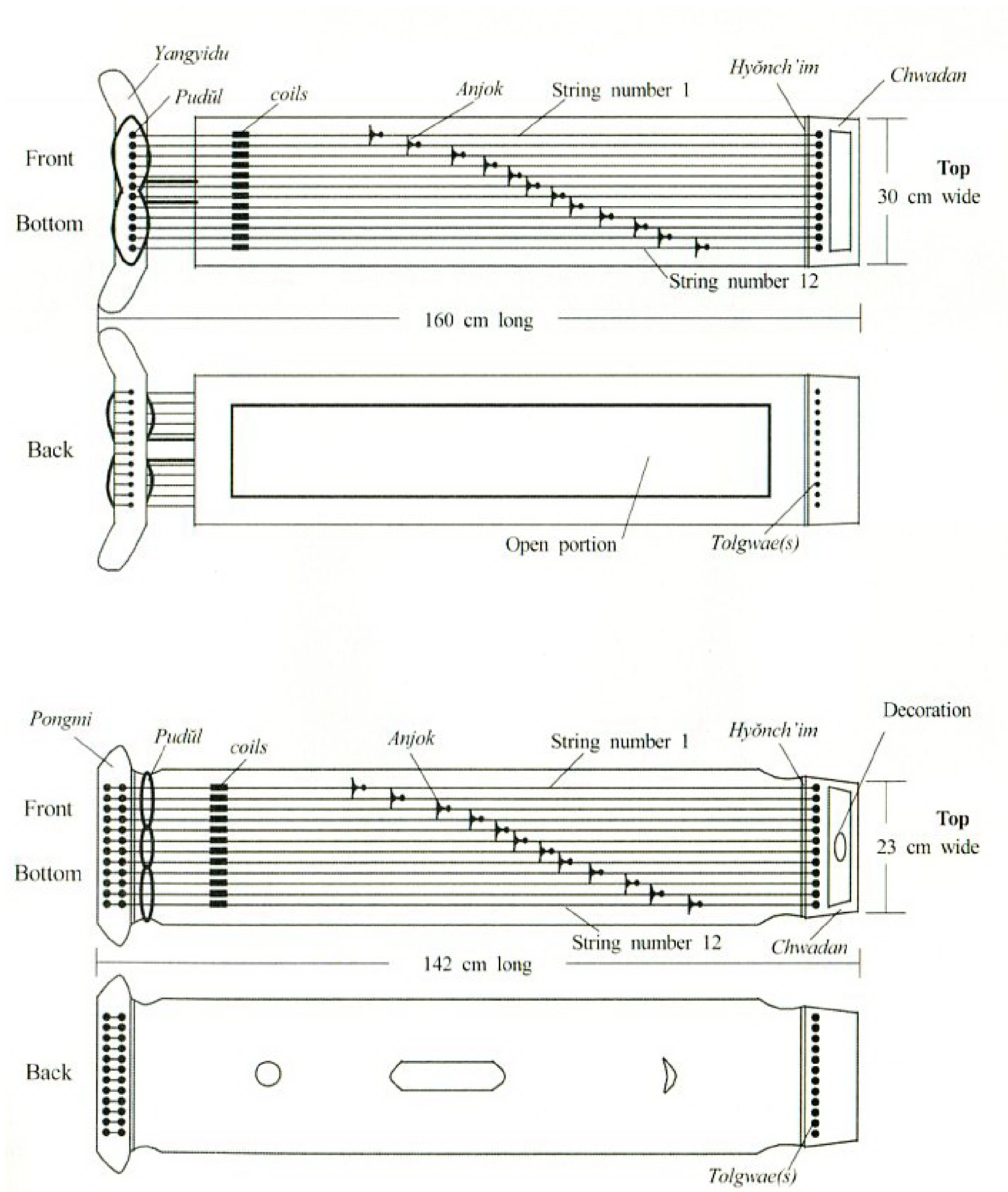


Figure 2.2.12 Diagram of Chongak Gayageum (above) and Sanjo Gayageum (below)

# 3. Background and Evolution of the Modified Gayageum

## 3.1 Controversy about the Necessity of the Modified Gayageum

Over time, there has been much debate about the necessity of the modified gayageum. The study of the debate explores a classic Gayageum's constraints and possibilities. This research serves as a critical design clue for the new instrument by adopting the traditional gayageum's essential features.

### 3.1.1 Criticism of the Necessity of Modified Gayageum

The people, who oppose the modification of the traditional Gayageum, do so based on three major arguments: First, they argue that the main purpose of Gayegeum's modifications was not to perpetuate or eliminate any musical or historical tradition, but was instead the result of the influence of Western music. Ji Young Jeon argued that Sanjo Gayageum, now about a century old, was also a modified Gayageum. Sanjo Gayageum, however, was designed within a very different context with modern modified Gayageum: modified Gayageum we can see today has been made to play contemporary music, while Sanjo Gayageum was created only to perform traditional folk music more efficiently.[21]

[21] Ji Young Jeon, "Another power, 25-stringed Gayageum", Journal of Culture & Arts 277 (2002): 60.

Second, opponents claim that the modified Gayageum's appearance diminishes the spirit of the traditional Gayageum because the amplified expression and pitch through the increased number of strings has ruined the original property and taste of traditional Gayageum. The subtle feeling of the left hand manipulation created from strings, and the dramatic expression of microtones generated from the Sanjo performer's emotions have been diminished by 25-stringed Gayageum's fast fingers and their appealing but otherwise arguably empty sound.[22]

Third, opponents criticize the modified Gayageum's string materials. Recall that the traditional Gayageum uses silk strings appropriate for the pentatonic scale, while the 25-stringed Gayageum uses rayon strings to extend the range of pitches. The 25-stringed Gayageum has a similar tone and technique to the Western culture's harp. Thus, opponents believe the spirit of the tradition disappears in the 25-stringed Gayageum.[23]

### 3.1.2 The Background of Modified Gayageum's Appearance

#### 3.1.2.A. The Background of Modified Instruments

First of all, various types of modified instruments, which were influenced by Western music, have been created to play contemporary music in modernized

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22 Jeon, *Another power, 25-stringed Gayageum*, 61.

23 Ji Young Kim, "Close and far Korean traditional Music: to find flavor of the traditional music," *Weekly Korea*, September 25, 2012, http://weekly.hankooki.com/whan/200102/w20010227210037615122 8.htm

environments. The cultural shift in Korean traditional music, which required the modification of instruments including Gayageum, led to many issues.

First, the improvement of humans' aesthetic sense has demanded a more accurate interval. Dae Woon Baek explains people's aesthetic sense changed when the concept of ensemble appeared in Korea via Western music since twentieth century. Traditional instruments do not have a standard pitch, so the inaccurate interval has caused a dissonance at the ensemble. Even the traditional instruments' inaccurate interval could not appeal to the public. That was because the public was familiar with Western music, which has a standard pitch with an equal temperament.[24]

Second, performers began to consider the concert environments. A loud sound was needed to play traditional instruments at the large theater or to perform collaboration with Western instruments. Traditional instruments do not reflect a volume of the sound since they had been played in a room or a small courtyard except for a few percussion instruments and brass instruments. As a result, a microphone was the only solution to loudening an instrument's sound before the appearance of the modified instruments. However, the microphone interrupted the traditional instruments' original tone. Thus, many performers argued that they needed a small-size theater that fit in traditional instruments' environments. This controversy led to the undeniable notion that the volume of

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24 Dae Woon Baek, "Aspects of the traditional music in the twentieth century," *Weekly Korea*, September 26, 2012, http://blog.daum.net/philos777/7145090

an instrument was a critical aspect of its design. This gave way to the consideration of the necessity of modified instruments.[25]

Lastly, problems such as inharmonious volume and unbalanced tones between instruments were raised in the ensemble of the orchestra or the chamber music. As a result, some people suggested modifying the traditional instruments partially in the aspect of an ensemble by keeping the traditional tone as much as possible.[26]

### 3.1.2. B. The Background of Modified Gayageum

Like its modernized versions, the traditional gayageum also has some controversy concerning its design. In this chapter, I will explore the modified gayageum’s background by focusing on the gayageum’s anatomy.

First, there is a sound problem in the traditional gayageum. Traditional gayageum do not have a standard sound system because of its unscientific fabrication process. This causes an inaccurate interval and imbalance with other instruments in an ensemble. In addition, movable bridges add to the interval problem. Each of gayageum’s strings is supported by a movable bridge. Although the gayageum performer does tuning just before the performance, the performer has to manage the movable bridges during his or her performance since the movable bridges easily move so easily and can cause unbalanced intervals.

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25 So Young Lee, “The Modification of the Traditional instrument and the present and the prospect of the discussion,” Romantic music 8-2, (1996): 55-56.

26 Lee, *The Modification of the Traditional instrument and the present and the prospect of the discussion*, 57.

The strings' material also causes an interval problem, too. Traditional gayageum's strings are composed of silk material. The silk strings have a unique tone. However, they are too weak in humidity and are sensitive in the temperature fluctuations. When a gayageum performer plays contemporary music using the traditional gayageum, the movable bridges excessively move. It breaks down the instrument's tone and ruins the elasticity of its silk strings. If the movable bridges move a lot, the performer has to spend a lot of time for tuning. Sometimes, the damaged strings are broken in the middle of the performance. That is because the silk string is weak in the tensile force. These problems prompted invention of the modified gayageum.[27]

Second, the traditional gayageum faced a volume limitation, making it difficult for audiences to hear its sound. Structurally, the coils of strings and the loops of cords not only disrupt the resonance of sound, but also reduce the volume (figure 3.1).[28]

Figure 3.1 Coils and loops of colored cords

Third, the traditional gayageum produces slightly rough notes in an ensemble.[29] Paying contemporary music with the traditional gayageum is challenging since the traditional gayageum could not reach the high or low

27 Kyoung Suk Suh, "Research of Modified Strings," (Arts and sciences research, Geonbuk province Gukakwon, 1998).
28 Han, "The Enhancement of *Gayageum*: Current Status & Perspective."
29 Han, "The Enhancement of *Gayageum*: Current Status & Perspective."

pitches necessitated by the composition of Western music, thereby also limiting its composition.[30]

Fourth, the traditional gayageum needed to be modified to play various types of music in a performance. Because the traditional gayageum has a narrow range of pitch, performers had to change their instrument or tuning to play various musical genres in a performance.[31]

Fifth, North Korea's modification of the gayageum influenced South Korea since the early 1990s.[32]

### 3.2 Types of Modified Gayageum

Modified gayageums such as 13, 15, 17, 18, 21 and 25-stringed gayageum all have relations with the boom of new Western music. The modification involves conductors, composers, performers, manufacturers, institutions, and traditional music orchestras. There are three main reasons for the creation of the modified gayageum. The modified gayageum evolved to increase its convenience, to increase volume, and to reflect the performer's specific needs. The modified gayageum has improved the convenience of the tuning system. The modified gayageum is easier to tune following the temperament of Western classical music thanks to the introduction of its tuning

30 Man-young Han, "Need not to focus on the traditional music," Music Donga 23, (1986): 182.

31 Han, "The Enhancement of *Gayageum*: Current Status & Perspective."

32 Han, "The Enhancement of *Gayageum*: Current Status & Perspective."

pegs. For example, the 18-stringed gayageum removed the traditional 12-stringed gayageum's wooden peg, and added metal pegs instead. The wooden pegs are located underneath the head of the gayageum. These wooden pegs attach the ends of strings (figure 3.2.1), while the metal pegs have a tuning function. These metal tuning pegs are hidden inside of the modified Gayageum's foldable head (figure 3.2.2).[33]

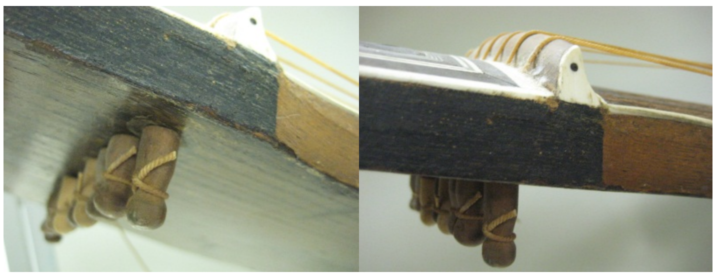

Figure 3.2.1 Wooden pegs of traditional Sanjo Gayageum

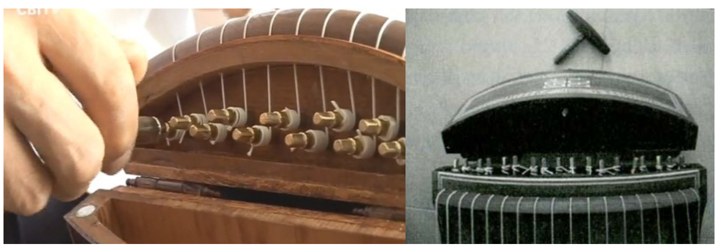

Figure 3.2.2 Metal tuning pegs of modified gayageum

The volume of the modified gayageum is larger, longer, and more box-shaped than the traditional Sanjo Gayageum. This resulted in one of the most critical requirements to meet the demands of Western music. New types of strings increased durability and amplified the sound. Usually polyester or mixed materials are used along with a bigger sounding box. The new strings are very durable which allowed the modified gayageum to no longer need cords and

33 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 238.

loops, which were connected to strings. The absence of cords and loops increased constancy in pitch. As a result, the modified gayageum produces a loud and sharp sound compared to the soft and deep sound of the traditional Sanjo Gayageum.[34]

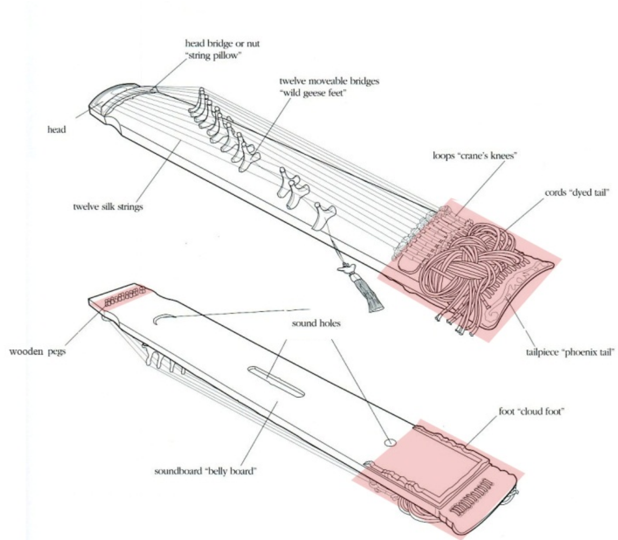


Figure 3.2.3 Sanjo Gayageum's removed parts in the modifided gayageum

Several modified gayageum were created by performers to solve their individual needs. Geum Yeon Song, a Gayageum Sanjo master, invented the 15-stringed gayageum and metal-stringed gayageum during the nineteen sixties. The gayageum enhanced the ease of the modulation by adding strings between the first and second, third and fourth strings, as well as above the twelfth strings of the standard Sanjo instrument. Pyong Ju Hwang, a former member of the KBS (Korean Broadcasting System) traditional Korean music orchestra, made the 17-stringed gayageum to help modulate from one key to another which often happens in an orchestra setting. Usually three different

34 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 239.

tunings were necessary in the traditional orchestra including Sanjo tuning, Chongak tuning, and folk song tuning, which required different tuning systems and in different ranges. The pitch of the gayageum varied depending on the location of the bridges requiring gayageum players to change their bridges to achieve different tunings. The 17-stringed gayageum is meaningful in that it helped the orchestra performers control the modulation without changing the bridges. The 25-stringed gayageum was invented by the well-known solo gayageum performer, Kim il-ryun for her premiere "New Sanjo" at the large theater. It added three more strings to the 22-stringed gayageum.[35]

Even if the development of modified gaygeum have become a critical part of the new gayageum music phenomenon in that the increased string numbers are useful in making Western harmony with wider ranges and registers, gayageum performers and critics believe that the most critical value of these modified gayaguem is in preserving its realistic gayageum sound. These critics claim that these modified gayageum just followed Western temperament and heptatonic scale by losing the identity of traditional gayageum. Critics argued that these modified gayageum only increased numbers of strings without any evocative, structural changes. In other words, they are basically the same instrument with different numbers of string and different names.[36]

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[35] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 239-240.
[36] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 240.

### 3.3 Modified Gayageum and Variations in Aesthetics and Attitudes

Modifications in musical sound have caused variations in aesthetics. New instruments have the advantage of producing louder sounds and varied textures including practical harmony. Thus, the potentials of acoustics are more diverse than traditional gayageum. In performing new music, accuracy is of the utmost importance while the flexibility and creativeness in melody, rhythm and microtonal shadings of musical expression are stressed in Gayageum Sanjo. Namely, exact pitches as written in the score should be emphasized by performance in new music. Musical accents, dynamics, and sharp and clear sound are principal features of the interpretation of new music. Modified gayageum is meaningful in that it allows for control of accuracy when tuning the instrument and when harmonizing within an orchestration of music. Sometimes the loose of strings of Sanjo Gayageum, for example, cause pitch variations during the performance. The sound quality of the traditional gayageum, however, is not appropriate for new music, particularly for ensemble music. In addition, tuning for modified gayageum is relatively less difficult in the ensemble performance.[37]

A variety of musical sounds is enabled by the invention of modified gayageum. modifed gayageum accommodates a larger scale of musical genres from classical music to modern Western music. Its advanced materials and expanded strings allow it to fit into modern concert halls. It gives quite the

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37 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 242-243.

competitive edge to Western music in Korea. Musicians declare that any type of music in Korea can be performed with modified gayageum by creating modern tradition independently of Westernization. The new gayageum music is often referred to by practitioners as “wearing modern-style dress with a traditional spirit.” The “dress” usually engages with musical structure, harmony, style, and particular musical expressions and “spirit” integrates specific traditional musical feelings of Korean music. The “dress” and “spirit”, in a sense, are interwoven to build one’s own sound in relation to the “modern tradition.” [38]

### 3.4 Historical Data of Traditional Gayageum and Modified Gayageum

Table 3.4 Traditional gayageum and modifed gayageum[39]

| Type of gayageum / Name | Year of Modification (Year of first appearance) | Type | Initiator | Material of Strings | Ranges and Scale of Tuning | Function / Initial Aim of Modification |
|---|---|---|---|---|---|---|
| Chongak Gayageum | 6C | Traditional | Woo Ruk | Silk strings | 2.5 Octaves Pentatonic | Original |
| Sanjo Gayageum | 19C | Traditional | Spontaneously generated to play Sanjo | Silk strings | 2.5 Octaves Pentatonic | For folk music including folk songs and recently |

[38] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 246-252.
[39] Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 237.

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | composed music |
| 15-stringed Gayageum | 1960s | Modified | Geum Yeon Song (Gayageum Sanjo master) | Same as traditional gayageum | 3 Octaves Pentatonic | For folk song, song accompaniment |
| Changgeum | 1976, 1985 | Modified | Ik Chang Chon (Composer/ performer) | Silk and metal strings | Low pitched High pitched Pentatonic/ Heptatonic | For new compositions Possible to amplify electronically |
| 21-stringed gayageum | 1985 (1986) | Modified | Sung Chun Yi (Composer/professor) | Polyester strings, no tailpiece | 4 Octaves Pentatonic | Enlargement of sound and registers |
| Bass Middle-pitched High-pitched gayageum | 1987 (1988) | Modified | Pom Hun Park (Composer/ conductor/ professor) | Same as traditional gayageum | 3 Octaves Each instrument with different range. Pentatonic | For the gayageum ensemble |
| 17-stringed gayageum | 1986-1900 (1991) | Modified | Pyong Ju Hwang (professor / former member of KBS kugak orchestra) | Polyester strings, no tailpiece | 4 Octaves Pentatonic | To perform different genres of music with one instrument exclusively for traditional music orchestra |
| 18-stringed gayageum | 1988 (1989) | Modified | Il Hun Pak (Composer) | Same as traditional gayageum, Triangle-shaped | 4 Octaves Pentatonic | Extension of gayageum registers |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | movable bridge | | |
| Modified Sanjo gayageum | 1988-1991 | Modified | Chi Ae Choi (Former member of KBS kugak orchestra) | Silk strings, Extra wooden plate (back) Extra wooden bridges (cords) | 3 Octaves Pentatonic | Amplification of gayageum sound |
| 22-stringed gayageum | 1995 (1995) | Modified | Pom Hun Pak (Professor / conductor/ professor) | Mixed material strings, Mono (based on Polyester), opened head | 3 Octaves Heptatonic | Amplification of sound, Pitch stability, especially for orchestra setting |
| 25-stringed gayageum | 2000 | Modified | Il Ryun Kim (Professor / Gayageum soloist) | Mixed material strings Mono (based on Polyester) opened head | 3 Octaves Heptatonic | For new compositions |

## 3.5 Inquiries to Design New 12-stringed Instrument

While studying modified gayaguem, I developed a particular inquisition regarding traditional gayaguem and creating a new cultural symbol by keeping traditional gayageum's spirit. What if the gayageum is produced through mass customization? What if the movable bridges have three or four legs instead of two to deliver more even vertical force to the instrument surface? In that case, the material of the instrument surface might be changed to thinner and weaker material like a paper. What if the silk strings could be used without coils, loops, and cords to make a loud volume and clear tone? In that case, the broken or damaged silk strings could be easily replaced. What if the body's size is increased by keeping twelve strings to increase the volume? What if the tuning is easily and quickly adjustable like the Western string instrument, the guitar?

# 4. Background and Evolution of Digital Design and Fabrication

## 4.1 Emergence of Digital Tectonics and its Cultural Influence

Throughout the twentieth century and into the twenty-first century, digital innovation and techniques have proliferated in the field of architecture. Le Corbusier, one of the most influential architects since twentieth century, described the significance of the advanced tools in the early twentieth century as follows:

> Architecture is one of the most urgent needs of man, for the house has always been the indispensable and first tool that he has forged for himself. Man's stock of tools marks out the stages of civilization, the Stone Age, the bronze age, the iron age. Tools are the result of successive improvement; the effort of all generations is embodied in them. The tool is the direct and immediate expression of progress; it gives man essential assistance and essential freedom also. We throw the out-of-date tool on the scrap-heap: the carbine, the culverin, the growler and the old locomotive. This action is a manifestation of health, of moral health, of morale also; it is not right that we should produce bad things because of a bad tool; nor is it right that we should waste our energy, our health and our courage because of a bad tool; it must be thrown away and replaced.[40]

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40 Le Corbusier, *Towards a New Architecture*, trans. Frederick Etchells (London: The Architectural Press, 1946), 17.

Students, professors, and professionals are all considering how to reshape architectural practice in our new digital environment. The digital revolution has deeply interpenetrated everyday life and the architectural field with the decrease in cost of 3D software, laser cutters, and computer numerically controlled (CNC) routers alongside the increasing power and speed of personal computers.

The earliest numerical control systems were made by the U.S. Air Force in the nineteen forties to fabricate accurate aircraft components. Then, these techniques were speedily adopted by other industries. Digital computers were used to design aircraft in the 1960s. The connection of computer-aided design (CAD) and computer-aided manufacturing (CAM) was adopted by other industries to produce complex-shaped products such as cars and ships in the 1970s and 1980s. Although the early CAD/CAM systems were only available to make high-volume products, over time the CAD/CAM and CNC fabrication began to proliferate other areas of industrial design and manufacturing resulting from quick growths in computing power and decreasing costs. From the nineteen nineties, three-dimensional forces began to emerge that dealt with both design practice and project delivery: building information modeling (BIM); intelligent, feature-based parametric modeling; and mass-customization. As these technologies became more cost-effective, more flexible, and more affordable, they began to infiltrate the architecture, engineering, and construction industries.[41]

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41 Robert Corser, ed., *Fabricating Architecture: Selected Readings in Digital Design and Manufacturing* (New York: Princeton Architectural Press, 2010), 13-14.

### 4.2 Contemporary Digital Fabrication Techniques

Lisa Iwamoto discusses in her research the development of five types of digital fabrication techniques that have emerged over the past fifteen years: sectioning, tessellating, folding, contouring, and forming.[42] These precedent projects present how architects have utilized digital techniques for design.

The first digital fabrication technique, sectioning. Iwamoto explains, "Rather than construct the surface itself, sectioning uses a series of profiles, the edges of which follow lines of surface geometry." Architects can instantly cut parallel sections through any object's shape at assigned intervals using digital modeling software's sectioning command.

The sectioning assembly has been utilized to create both surface and structure not only by architects, but ship builders and airplane builders as well for quite some time now. Boat hulls are defined as a series of structural ribs that represent sections through the hull. Then the hull is cladded by a surface material. [43] Le Corbusier, in the pre-digital era, designed a series of concrete ribs, which were tied together laterally by crossbeams, in the roof of the chapel at Ronchamp.[44]

*Dunescape* which was built by SHOP Architects in 2001 is an architectural landscape built as a series of parallel lumbers. It shows how

[42] Lisa Iwamoto, Digital Fabrications: Architectural and Material Techniques (New York: Princeton Architectural Press, 2009), 4.
[43] Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 10.
[44] Le Corbusier, Ronchamp, translated by Jacquelaine Cullen (Stuttgart: Verlag Gerd Hatje, 1957), 92.

the digitally driven process could be built on the site. First, the digital model was sectioned at intervals. Then, the material thickness was given to sections. The final section drawings were plotted at full scale to layout each wood piece.[45]

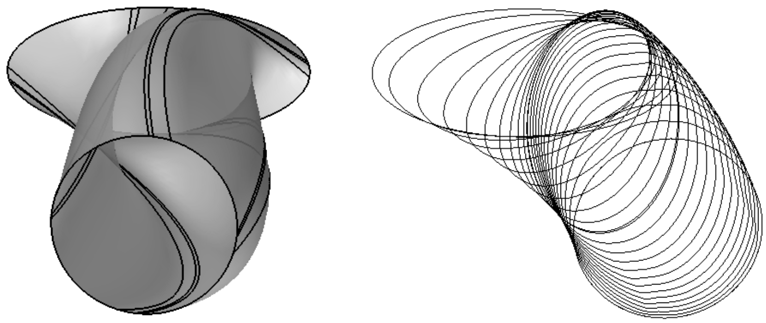

Figure 4.1 Example of cutting sections using contour command in Rhino3D

Figure 4.2 *Ronchamp chapel* scaled model showing ribbed roof structure, 1950

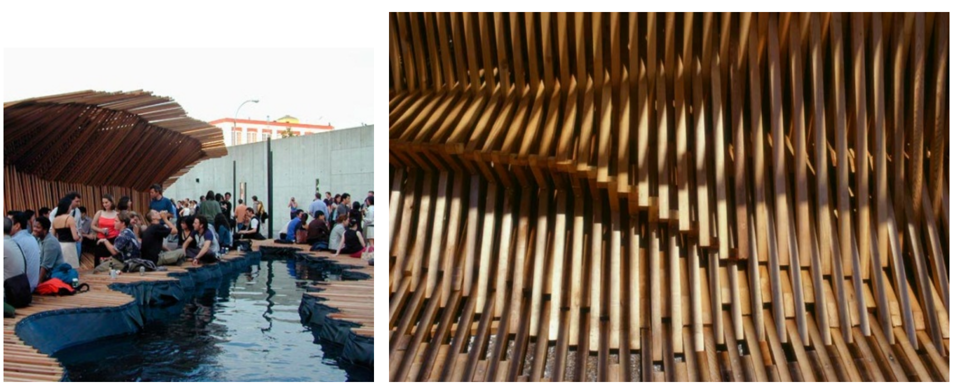

Figure 4.3 *Dunescape*, 2001

45 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 12.

The second digital fabrication technique is tessellation which Iwamoto explains, "is a collection of pieces that fit together without gaps to form a plane or surface. Tessellations can be virtually any shape so long as they puzzle together in tight formation." [46] Typically, curved surfaces are far more expensive than flat ones to construct. Architects can reduce a lot of time and cost by using tessellation to build a smooth form with standard-size sheet materials. 3D modeling software such as Rhino3D has the powerful function of not only creating sections but also generating tessellation patterns based on free form surfaces. The tessellation patterns can be controlled by architects as a parametric modeling. It means that once architects set a tessellation pattern in the surface, the pattern remains although the shape of the surface changes infinitely. Then, the pattern can be revised at any time based on the changed shape. This is the evolution of the drawing since architects need not delete objects or the assigned pattern like Autocad drawings. Rather, they can simply revise them according to appropriate situations. The evolution of 3D software offers various design strategies to architects by allowing them to choose a way to approach the optimization of free form surfaces. For example, the BMW Welt designed by Coop Himmelblau in 2007 exemplifies the immense advantage of tessellation in that it could be utilized in the multiple scales and curvatures. The panel shapes and scale vary from rectangular shapes at the ceiling to triangular shapes with a halved scale at the boundary with the corn. The flat glass panes

46 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 36.

reduce the triangular geometry. The tiling strategy reflects the dynamic force of the structure.[47]

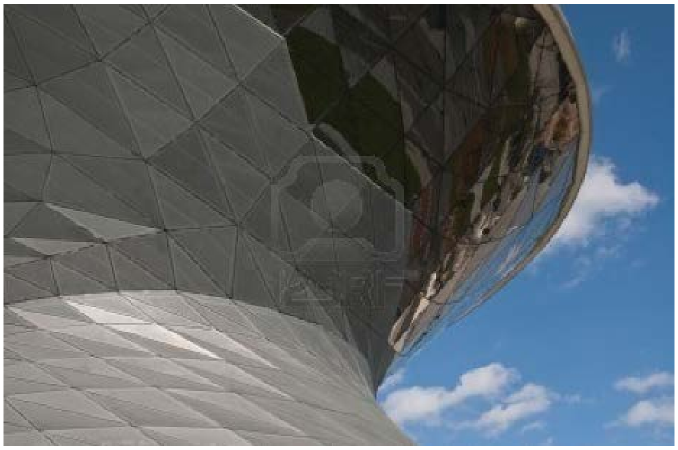

Figure 4.4 *BMW Welt*, Munich, Germany, 2007

The third digital fabrication technique is folding. "Folding," Iwamoto explains, "turns a flat surface into a three-dimensional one." What is most remarkable about folding is that it allows for two things to be accomplished at once: the development of both the form and structure. According to the folding strategy, materials can get stiffness, can span distance, can apply at various scale, and can self-supporting with economic cost and visual aesthetics.[48] EMERGENT and Buro Happold reinterpreted dragonfly wing as an extreme cantilever structure called *Dragonfly* using folding technique for the SCI-Arc Gallery in 2007. To achieve the cantilever condition, EMERGENT and Buro Happold tried to establish a digital optimization routine to refine the structure, as well as utilize a parameterized fabrication process. The three-dimensional computer work and the two-dimensional CAD template were linked together.

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47 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 40.
48 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 62.

Design team used 3D software CATIA to describe each member accurately, including bolt holes, material thickness, and scored seams. They were also digitally labeled including the information of bending angle and location. These templates were arranged using Rhino3D on a four-by-eight-foot aluminum sheet and then cut using CNC router. Digital fabrication, though have high accurate, still have limits to deal with material fluctuations and properties. Iwamoto referred, “Building *Dragonfly* was no exception.  Slight deviation in bending the angles and folds, as well as in the expansion and contraction of the aluminum, naturally created unanticipated consequences.” Thus, it is an efficient process to learn the margin of error of materials through design-build experiment at one to one scale before the rush to the final assembly. [49]


Figure 4.5 *Dragonfly*, SCI-Arch, USA, 2007

49 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 67-68.

The fourth digital fabrication technique is contouring. Iwamoto explains this technique: “Construction materials typically come as sheets. Contouring is a technique that reshapes this surface and creates a three-dimensional relief by removing successive layers of material.” There is a long history of wood and stone carving in architecture. Rock-cut architecture, ordered Greek-columns, and friezes are all carved by hand. Digital fabrication enabled architects to adopt the idea of traditional handcraft to apply in the ordinary sheet materials.

Contouring is time and material intensive work. In the process, CNC mills removes materials from virgin sheets to make parts which produce a significant amount of waste. Thus, this technique is limited to only being utilized at the scale of the building.[50] *Design 306* designed by Erwin Hauer and Enrique Rosado in 2005 used a three-axis CNC mill using Indiana limestone. The panel size is ten feet by four feet, while the dimensions of the modules within the pattern are fourteen inches high by eleven inches wide.[51]

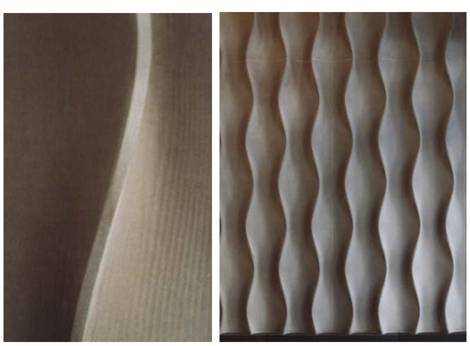

Figure 4.6 *Design 306*, New York, 2005

50 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 90-93.
51 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 98.

The last digital fabrication technique is forming. Formed objects are everywhere around us. However, the digital forming process is highly valued for allowing architects to produce non-standardized manufacturing cost effectively.[52] P_Wall, an example of forming, was designed by Andrew Kudless in 2006 is the investigation of the self-organization of plaster and elastic fabric to produce evocative visual and acoustic effects.[53]

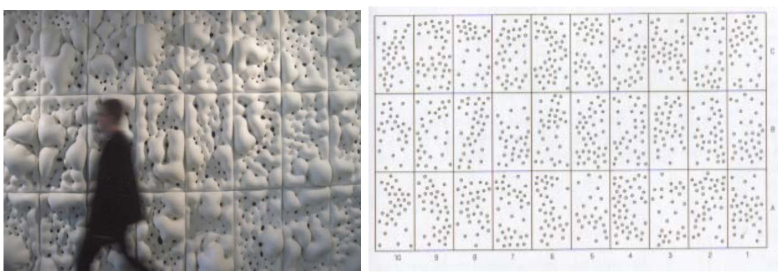

Figure 4.7 *P_Wall*, 2006

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52 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 108.
53 Iwamoto, *Digital Fabrications: Architectural and Material Techniques*, 138.

# 5. Case Studies: Examples that Created a New Tradition by Interpreting History and Tradition as a Means to Fit Modern Lifestyle

## 5.1 Clothes of Wind Designed by Hanbok Designer, Young-Hee Lee

Hanbok, the traditional clothing of Korea, was a part of the distinctive culture of Korea. Hanbok has evolved and inherited to today since it appeared about two thousand years ago. Korean clothing culture was influenced by new clothing cultures through the numerous invasions from foreign countries (e.g., China, Northern Scythian) [54] as shown in Hanbok Kusong, "it was brought into Korea when one of the princes married a princess of a colony in China" and also through Buddhism.[55]

Hanbok blends the soft curve lines with the straight lines. Women's Hanbok consists of top and skirt. The top is quite short which stretches only down to the upper belly, while the skirt is long. Men' Hanbok consists of jacket, vest, and pants.

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54 "Hanbok," http://www.han-style.com/english/hanbok/meaning.jsp (accessed December 06, 2012)

55 "History of Hanbok," http://www.ctahr.hawaii.edu/costume/StudentProj/hanbok/02.html (accessed December 06, 2012)

Over many centuries, Hanbok has been slightly changed. Throughout various eras, Hanbok had a different length top, sleeve size, and skirt fullness. In the Ancient period, Han Bok was mainly comprised of a jacket and pants. Both men and women wore large pants which was a fashion statement that originated from Northern Scythian culture. This nomadic tribes' clothing, i.e., pants, was aimed at accommodating the cold weather and the nomadic lifestyle. The top was so long that it covered the wearer's calves and tied at the lower bottom of the waist. This style of Hanbok is shown on a wall painting of Muyoungchong, an ancient tomb of Goguryeo (B.C. 37 – A.D. 668) (figure 5.1).[56]

Figure 5.1 *Female Dancers in Muyoungchong*, Korea

In the Three Kingdoms period which included Goguryeo Kingdom (B.C. 37 – A.D. 668), Baekjae Kingdom (B.C. 18– A.D. 660), and Shinla Kingdom (B.C. 57 – A.D. 935), the top was characterized by a line pattern design and its unusual

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56 "History of Hanbok," http://www.ctahr.hawaii.edu/costume/StudentProj/hanbok/02.html (accessed December 06, 2012)

lengthiness. Women wore the skirted version of this ensemble while men wore the pants.[57]

Figure 5.2 Female Hanbok in Three Kingdoms period in Korea

During theJoseon Dynasty period (1392-1897), there was a variety of outewearfor men. As for women's Hanbok, the top was short and fancy. It is important to note that over time, women's tops became shorter and the skirts became fuller (figure 5.3 and figure 5.4).[58]

57 "Changed Styles in Hanbok" http://www.ctahr.hawaii.edu/costume/StudentProj/hanbok/03.html (accessed December 06, 2012)

58 "Changed Styles in Hanbok" http://www.ctahr.hawaii.edu/costume/StudentProj/hanbok/03.html (accessed December 06, 2012)

Figure 5.3 Woman's Hanbok (left)/ a genre painting (right) painted by Yun-Bok Shin, 18-19th century, Korea


Figure 5.4 Evolution of the Coat in Woman's Hanbok in Josun period, Korea

Today, comforts and fashion are the most important components of clothing design. The length of the top varies based on wearers' needs and the skirt remains the same style as that of the Joseon Dynasty, though slightly less grand in size.[59]

Figure 5.5 Modern Hanbok, Korea

Young-Hee Lee is one of the most influential Hanbok designers who took on the challenge of balancing color and creative daringness with the natural beauty of the traditional style. Since Young-Hee Lee's designs of the hanbok design debuted in Paris on March 1993, she continued to introduce unique Hanbok designs that reflect Korean culture. Every year her unique Hanbok designs act as a representation of the possibility of the globalization of Hanboks as they reinterpret traditional spirit into the modern life style. The main character of Young-Hee Lee's Hanbok goes as follows: 1) In silhouette, Young-Hee Lee's Hanbok represents natural beauty by focusing humble and rusty aspect of traditional Hanbok's image. 2) In material, Young-Hee Lee mainly used natural material such as cotton and ramie fabric (모시). 3) In color, Young-Hee Lee

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59 "Changed Styles in Hanbok" http://www.ctahr.hawaii.edu/costume/StudentProj/hanbok/03.html (accessed December 06, 2012)

represents dual delicacy that becomes lighter in the daylight and deeper in the shade using various shades of white, grey, yellow, red, and blue.

The revelation of the inside sentiment of Koreans tradition of utilizing silhouette, material, and color creates a uniqueness that reflects the culture's tradition. This is a good example of how new tradition is created by transforming traditional wear into semantics of the times.

"Clothes of Winds", is a topless, skirted take on Women's Hanbok, and is one of Young-Hee Lee's most representative works (figure 5.6). The "Clothes of Winds" not only broke the mold of Hanbok, but also brought an element of natural beauty to the traditional Hanbok is a modern yet traditional Korean style that infinitely represents the essence of beauty in Korea.

The "Clothes of Winds", paradoxically, were created in Paris. In Paris, the exposure, which inspired the concept of the "Clothes of Winds", was the general trend. Young-Hee Lee said, "If I was not in Paris, it [would have been] impossible to create 'Clothes of Winds' since my creativity [would] be confined [by] the traditional Hanbok."[60]

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60 Young-Hee Lee, Hanbok Designer who went to Paris (Seoul: Design House, 2008), 13-14.

Figure 5.6 *Clothes of Wind* by Young-Hee Lee

The feeling of Wind fit into the Hanbok skirt rather than the jacket. The form and silhouette of the skirt varies by the wind: The silhouette sometimes catches the wind and often flutters in the wind. One might even argue that the Hanbok skirt itself *is* a wind. The idea of “Clothes of Winds” was realized at the Collection stage in Paris on October, 1994. Its material, “nobang”, is one of the traditional fabrics of Hanbok: The skirts’ drawstrings and panels were all made of the same material and color with only varying texture (figure 5.7). The form of the skirt followed that of the traditional Hanbok skirt and has an open back. After a few years after her modern take on the Hanbok, Young-Hee Lee changed the form of skirt by shifting this opening to the front of the skirt instead. This daring shift in thinking created a lightening effect and a more modern feeling by exposing the leg as the skirt moves. The Clothes of Wind were a realization of a modern style of dress that has “a feeling of Korean [culture]” rather than acting solely as a representation of the Hanbok.[61]

61 Lee, *Hanbok Designer who went to Paris*, 14-20.

Figure 5.7 Hanbok fabric “nobang”, Korea

“Clothes of Winds” has evolved with various modifications in light of traditional lifestyles. In the past, for example, Korean women tied up their skirts with a string when they worked in their houses. Young-Hee Lee adopted the image into “Clothes of Winds”. She controlled the length and silhouette of the skirt by binding the waist. In doing so, ““Clothes of Winds”” is often seen as an Avant-Garde image by leaving one side tied and the other is left hanging to create an asymmetrical effect and appearance. Otherwise, the front of skirt can be shortly upraised and the back of skirt can be longer and left untied.[62]

“Clothes of Winds” maintained one distinctive characteristic of the traditional Hanbok skirt, which is its ability to unfold to a piece of plane. This piece of plane can replicate any silhouette, no matter the complexity of its shape. Unlike the Western dress, which is cut three-dimensionally. People can wear the Western dress only in its fixed form limiting its use to only human clothing. The

62 Lee, *Hanbok Designer who went to Paris*, 20-22.

Hanbok skirt, on the other hand, not only creates various silhouettes according to dressers' body types, but also transforms to be used for various reasons.[63]

This emphasis on utility is a major difference between Western philosophy and Eastern philosophy. The Western bag is made with a three-dimensional framework, therefore can only contain particular sized objects (figure 5.8). In addition, if the use of the bag changes, the bag itself changes as well. A wrapping cloth in Korea, on the other hand, serves the same purpose as a Western bag but is far more utilitarian (figure 5.9). The use of the wrapping cloth is endless depending on what it is filled with and its shape varies according to the form and contents of objects it's filled with. This same cloth meets so many other needs like moving objects, clothing a person or keeping a person warm.

Figure 5.8 Western bag, France

Figure 5.9 A wrapping cloth, Korea

63 Lee, *Hanbok Designer who went to Paris*, 22.

The same way the Western dress has its limitations, so does the Western architectural design of a house. While a Western house has several rooms that have a specific use, the Korean traditional house has one room that is used as a bedroom, library, and dining room making living in one very cozy although its physical scale is relatively small. In this sense, the Clothes of Wind, which reflects Korean traditional sensibility, is meaningful in that a piece of a plane like that of the Clothes of Wind has a limitless potential just as the wind endlessly transforms and moves with no fixed form.[64]

The Clothes of Wind wears not only as a skirt, but also a cloth that can wears as an entire ensemble mimicking a full form dress and, can be further accessorized with a piece of outerwear such as a jacket. Since the Clothes of Wind is from the traditional Hanbok, the addition of outerwear tends to balance the style of Clothes of Wind perfectly.[65]

The "Clothes of Winds" are created by breaking a fixed idea of traditional Hanbok, yet accuratey reflects traditional Hanbok's spirit and concept. It is a cloth that is extremely similar to Hanbok, but it is a cloth that is not Hanbok. It is a cloth that endlessly varies, but returns to the simplest flat surface. This vitality, which reflects modern lifestyle, is a reinterpretation of Korean tradition.

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64 Lee, *Hanbok Designer who went to Paris*, 22-23.
65 Lee, *Hanbok Designer who went to Paris*, 23.

# 6. Gayageum 3.0: Experiements of the Reinterpretation of Gayageum

## 6.1 Introduction

In architecture, it is essential to understand not only the tectonics of assembly, but to also be able to communicate these concepts to manufacturers as necessary. The digital age has made architectural design virtually limitless as changes to parametric data are done simply by using computing power. The introduction of digitization to architecture allows architects an immense amount of design freedom. However, with this freedom comes the challenge of ensuring they are able to communicate their imaginative designs to those who construct them. In most cases, three-dimensional structures are composed of two-dimensional materials, so the understanding and the representation of assembly logistics are critical in the design-build process. This assembly logistics not only can be applied to the reinterpretation of Gayageum, but its architectural structure as well.

My interest at the School of Architecture in University of Hawaii at Manoa was initially digital fabrication and has extended to include local identity not to exclude local culture, tradition, lifestyle, and local materials by utilizing digital fabricating technology. Though I admired the aesthetics of architectural design anywhere I went, my passion for architecture made it impossible for me to overlook the lack of cultural integration. Simply put, seeing so many works of digital fabrication throughout the world, I felt a sense of emptiness as most of them do not take into account local identity. The lack of cultural integration, I believe, somewhat undermines the genius of architectural design by dismissing the uniqueness of cultural identity any design would otherwise have if its designers would be more cognizant of local cultural influences (figure 6.1.1).

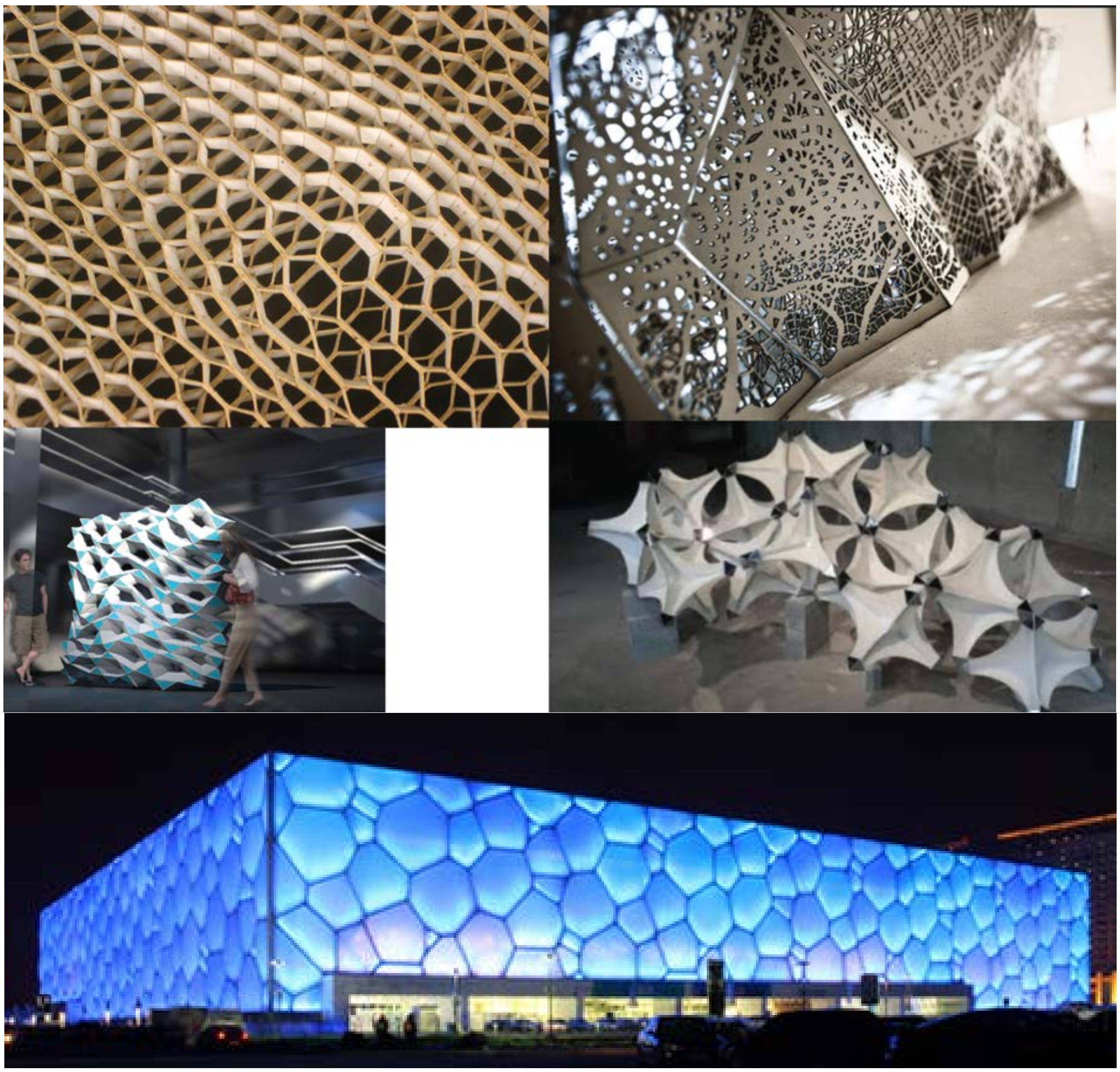

Figure 6.1.1 Digital fabrications throughout the world

In the experiment of Gayageum 3.0, I integrated the identifying factors of Korean culture by adopting folding tectonics from contemporary digital fabrication techniques as researched in Chapter 4. The goal of the Gayageum 3.0 is to give a message of localization of global digital technologies using gayageum as the medium (figure 6.1.2).

Figure 6.1.2 Tradition in Korea, Moon Jar 17C AD (left); painting by Yoon Bok Shin 18C AD (middle); Windows and doors in Dosan Seowon 16C AD (right)

## 6.2 Gayageum 3.0

I chose to name my design-build project *Gayageum 3.0* to emphasize the concept of global connection, which signifies the continuous evolution of my research in 2013, which is inspired by Globalization 3.0 as defined by Thomas L Friedman. Friedman argued that Globalization 1.0 was the initial globalization of countries, Globalization 2.0 was the onset of industrial globalization, and Globalization 3.0 is the globalization of individuals to unite and compete globally.[66] In the same way Globalization has evolved, the Gayageum also has evolved from Gayageum 1.0 to Gayageum 2.0 as well as to Gayageum 3.0.

Gayageum 1.0 represents the relationship between Korea and China which began in the sixth century in Korea. The original design of gayageum, which is called Chongak Gayageum, was influenced by the Chinese string instrument Zheng.[67] In the nineteenth century, the Chongak Gayaguem has evolved to Sanjo Gayaguem to reflect Korean folk music (figure 6.2.1).


Figure 6.2.1 Gayageum 1.0 diagram (left); Chongak Gayageum 6C AD(middle); Sanjo Gayageum 19C AD (right)

Gayageum 2.0 describes the linkage among Korea, China, and Japan, which began in the nineteen sixties in Korea. In this era, Korean people were influenced by Western music which has a wide range of pitch. It has changed the environment of performance from small theaters to concert-sized venues which requires a much more amplified playing volume capacity. This increased playing volume capacity also allowed musicians to play gayageum in musical

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66 Thomas L. Friedman, *The World Is Flat 3.0: A Brief History of the Twenty-first Century*, (New York: Picador), 10.

67 Kim, *Contemporary Kayagum Music in Korea: Tradition, Modernity and Identity*, 31-32.

ensembles. All of these changes, many have argued, is the Westernization of the gayageum, or, at the very least is the result of Western influence. Even today, Korea imports gayageum materials from China and Japan (figure 6.2.2). These social and cultural phenomena have led to the diminishment of the traditionally Korean cultural identity of gayageum.

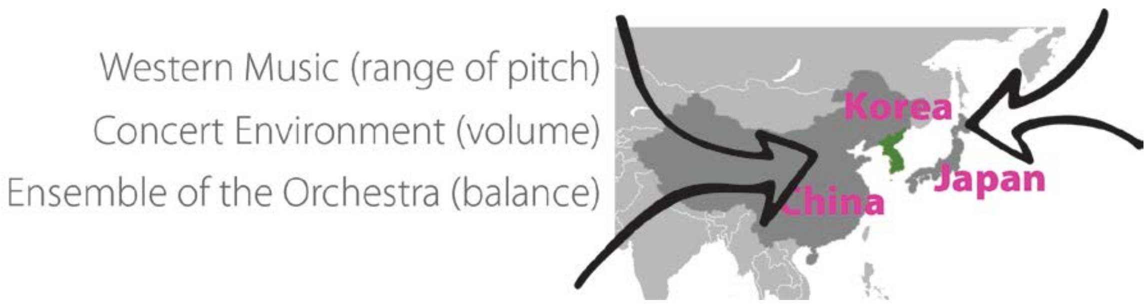


Figure 6.2.2 Gayageum 2.0 diagram (top); modified 25-stringed gayageum (bottom)

Gayageum 3.0 represents the connection between Korea's inclusiveness to globalization. The goal of my design project is to create a new cultural symbol by interpreting existing symbols using digital assembly logistics to incorporate design, culture, tradition, and contemporary architecture. It is a connection between traditional identity and global digital technology. I believe Gayageum 3.0 serves as a critical turning point for those who not only use digital technologies, but also play gayageum by forcing them to consider their identity within and contribution to the global age (figure 6.2.3).

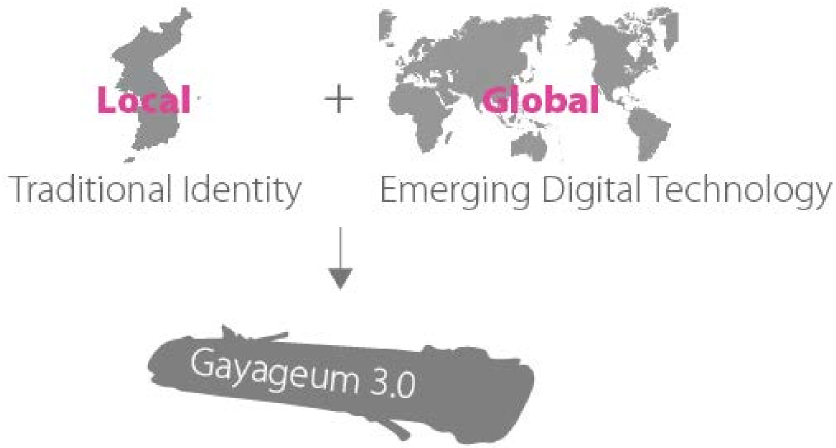


Figure 6.2.3 Gayageum 3.0 diagram, 2013

### 6.3 Design Methodology and Lifestyles in Korea

My design methodology is to experiment with the reinterpretation of gayageum using emerging digital tectonics reflecting traditional Korean lifestyles. This methodology stresses the importance of the definition of lifestyle to the design process. Of the thousands of various lifestyles in Korea, I chose to focus on just two to clearly represent the design idea and process. Further explanation of these two chosen lifestyles are explained in the following sections.

### 6.3.1 Lifestyle: Porous Boundary

The first lifestyle centers around a porous boundary, which is inspired by traditional Korean paper, which has been used to construct windows and doors in traditional Korean houses. In these traditional homes, the indoor and outdoor walls are subtle and porous. Jonathan Hill, author *of Immaterial Architecture* describes this architectural technique: “As windows are faced in opaque rice paper, oiled to become waterproof, the user’s perception of the exterior involves all the senses rather than the primarily visual connection between inside and outside that is apparent through the glass wall of the modernist open plan.”[68]

Reflecting on my own memory of the Korean traditional house where I grew up, I can recall how much the paper construction of my home affected my day-to-day thoughts and overall lifestyle. I could hear every sound in the house including my parent’s discussion in the next room, rain in the courtyard, friction of bamboo trees blown against each other by the wind, and the song of birds. I could smell the fragrance of earth on a rainy day in my room. During the daytime, I could feel a certain restfulness and warmth in the room since the soft shadows were dimmed through paper doors while direct sunlight was blocked by deep eaves. Sometimes the contrast between dark shadows and soft shadows created a beautiful harmonious sight. Whenever in my room, the space around me never felt empty as my sense were always stimulated by the

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[68] Jonathan Hill, *Immaterial Architecture* (Abingdon: Routledge, 2006), 168.

architecture of the room. The flexibility of furniture allowed the room to easily transform. A dining table, for example, can be folded and easily tucked away for later usage. Beds can be folded away during daytime. This is all exemplary of Hill's description of how the porous quality of paper diminishes the boundary that intercedes indoor and outdoor. I represent the materiality of the paper in the Gayageum 3.0 by using it in the structure and surface of instrument body (figure 6.3.1).


Figure 6.3.1 Namchon House, Korea 18C (top); Korean traditional paper (bottom)

### 6.4.2 Lifestyle: Sentiment

Sentiment is the second lifestyle I chose to study. It is inspired by the traditional Korean painting titled, *Listen a Song of Bird on the Horse* drawn by Hong Do Kim in the eighteenth century. In light of the realization that painting as an art form reflects culture and lifestyle in a society, I analyzed design elements from the composition of the painting to inspire ideas for the form, structure, and pattern design of Gayageum 3.0 (figure 6.3.2).


Figure 6.3.2 *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (left); design elements analysis from the composition of the painting (right)

### 6.3.2.A Taking and Throwing Away

Taking and throwing away, as I chose to call it, is the process of selecting critical elements and removing unnecessary factors. In the instance of the analysis of the painting, without taking the painting would not only lack configuration, but would also lack definitive composition. Without throwing away, if you will, the painting would lose its composition as the appropriate hierarchy of the elements of composition would be lost, thereby diminishing the artistic form of the painting (figure 6.3.2.A.1).[69]

Figure 6.3.2.A. *Entrance of Rock* by Jung Sun, Korea, 18C

[69] Baik Min Wang, *The Composition Theories of Oriental Painting*, as translated by.Gwan Sik Kang (Seoul: Mi Jin Sa, 1991), 9.

### 6.3.2.B Depiction of Strength

The strength in this Korean painting is the sense of movement of the shapes featured in it. If you look at the painting, examples of this include the shapes depicting motion upward, downward, toward the earth and sky. The mountain, for example, gives a feeling of intimacy while others objects in the painting induce a feeling of surprise in its onlookers. Sae Hwang Kang vividly represented a sense of rhythm in his painting by emphasizing the description of the strength (figure 6.3.2.B). Without rhythm, there is no feeling of movement. The painting might be recognized as a map or an architectural plan.[70]

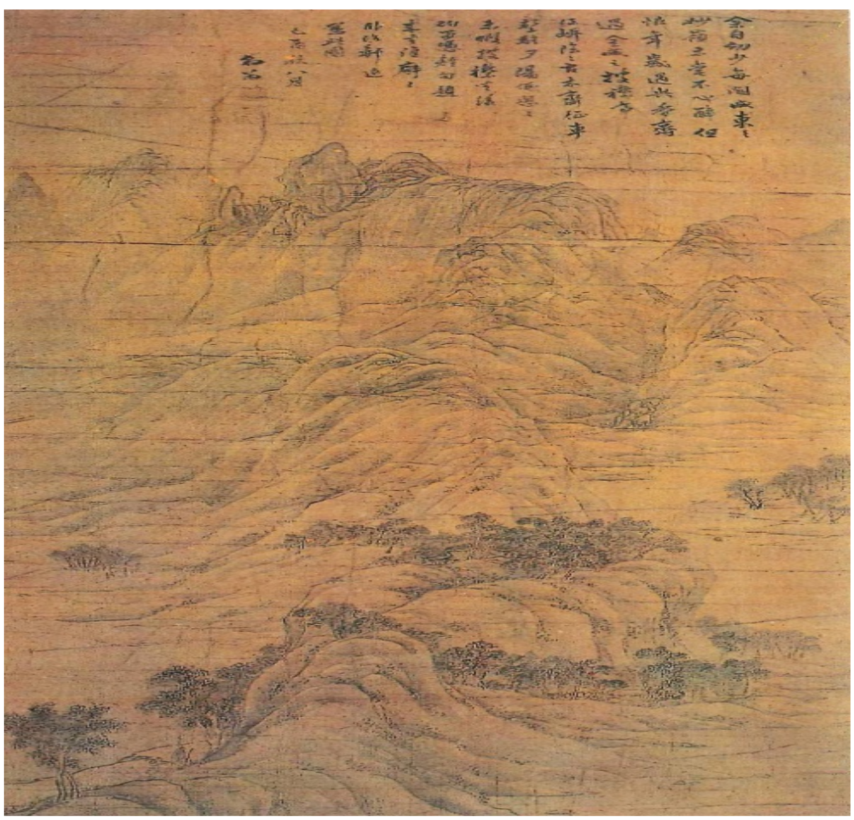


Figure 6.3.2.B. Pavilion on the Mountain by Sae Hwang Kang, Korea, 18C

[70] Wang, *The Composition Theories of Oriental Painting,* 27-35.

### 6.3.2.C Harmony

Harmony in Korean painting is created by allowing shapes to interconnect. There are two types of harmonies including superficial harmony such as action or expression and intrinsic harmony such as storyline or the mental state of a person. The painting titled *Dig the Spring along the Herb Basket* only shows a woman looking at an unspecified object with a herb basket and a garden hoe in hand. She, however, evokes us to wonder what she may be looking at-- a farmer or her children or something else? In this way, she is creating harmony by leading our minds to wonder about the someone or something that is not shown in the painting. There is a feeling of the fragrance of the spring at the same time (figure 6.3.2.C).[71]

Figure 6.3.2.C. *Dig the Spring Along the Herb Basket* by Yong Yoon, Korea, 18C (left); *Spring* by Yoon Bok Shin, Korea, 18C (right)

[71] Wang, *The Composition Theories of Oriental Painting,* 40-47.

### 6.3.2.D Large Space and Small Space

In Korean painting, actual things can be clearly represented by creating space. There are two types of spaces including large space, which is placed in a large scale, and small space, which is located in between shapes. Jung Sun's painting titled *Summer Time* illustrates large space at the edge and small space in the waterfalls. The coherence of small space and large space brings the mountain to life, so to speak, by giving it a dimension that, without proper usage of spatial elements, would be lost on the two-dimensional paper (figure 6.3.2.D, left). The painting titled Ducks has a large space at the center and small space in the rock and above the branch (figure 6.3.2.D, right).[72]

Figure 6.3.2.D *Summer Time* by Jung Sun, Korea, 18C (left); *Ducks* by Deuk Shin Kim, Korea, 19C (right)

[72] Wang, *The Composition Theories of Oriental Painting,* 52-64.

### 6.3.2.E Looseness and Density

To understand this, consider the typical feature film. There is a sequential storyline in all movies (good ones, at least) that includes looseness, intensity, pleasure, anger, depression, and a climax. The soundtrack in a movie directs our emotions with various tones and rhythms in the music. Without the loose and dense rhythms, slow and fast tempo, and high and low pitched tones, the filmmakers' intended reactions might be lost upon their audiences. This same concept of looseness and density are pertinent to the art of painting as well (figure 6.3.2.E).[73]

Figure 6.3.2.E *Moon and Apricot Flower* by Mong Yong Uh, Korea, 16C

[73] Wang, *The Composition Theories of Oriental Painting,* 75-79.

### 6.4 Concept

The concept for my design-build project was largely inspired by the artistic piece below, “Through the Reverberation of the Paper” (figure 6.5). It reads:

The skin of Paper Mulberry has been transformed into paper

Embraces the sound of Korean life

Hear the reverberation of paper

Resonance of space

Profound and subtle

Running through porous boundaries

Toward nature

Soft shadows are cast through translucent skin

Feel warmth and repose

Throughout the vibration of the paper

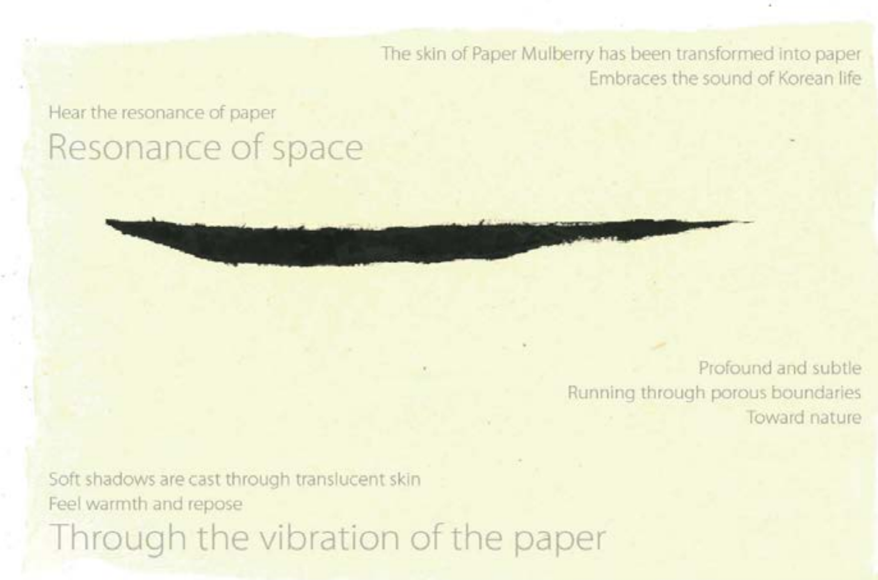



Figure 6.4 Gayageum 3.0 concept , “Through the Reverberation of the Paper”

## 6.5 Form

### 6.5.1 Perception of Modern People

The culture in Korea has drastically changed throughout the centuries. Today, Koreans' perception differs greatly from those in the eighteenth century. People, for example, are more aware of and active in events, news, readings, and works via digital media. Most media tools including digital TV and computer monitors, which have a resolution of 1920 x 1080, and an aspect ratio of 16:9 that reflects the human vision aspect ratio.

### 6.5.2 Form Design Framework

I set up the design framework for the design of the form of Gayageum 3.0. The design framework is based on a sketch that interprets the composition of *Listen a Song of Bird on the Horse* drawn by Hong Do Kim in the eighteenth century. The sketch is the reproduction of the gayageum performance's image. The method of the sketch was to redraw the gayageum player and the gayaguem on the tracing paper, which traces the gayageum player's photo, with a paper which has a ratio 16:9. This sketch, which has 16:9 ratio, not only creates the design of gayageum 3.0, but also merges the sense of tradition and modern.

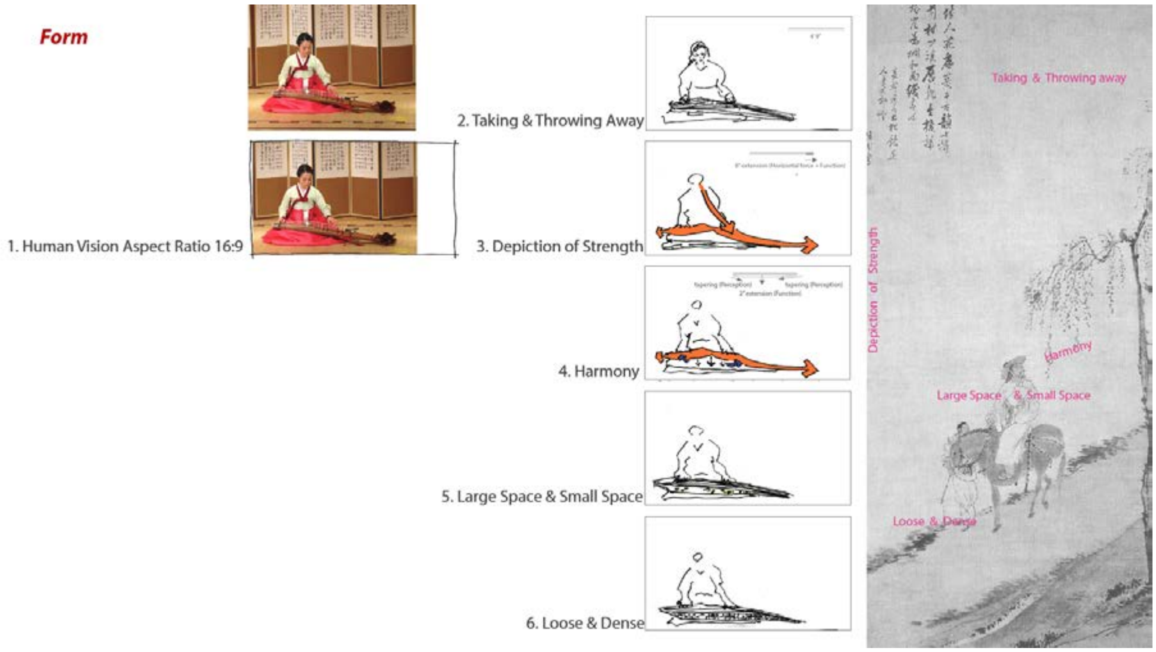



Figure 6.5.2 Form design framework

### 6.5.3 Form Design Process

First, I adopted a photo of a gayageum performance as a base for the sketch (figure 6.5.3.A).

Figure 6.5.3.A Image of gayageum performance

Second, the photo was adjusted to fit into the aspect ratio 16:9 (figure 6.5.3.B).


Figure 6.5.3.B Human Vision Aspect Ratio 16:9 (left)/ Digital TV in modern society (right)

Third, I drew a new sketch by tracing the photo of the gayageum performance. To develop the sketch, I utilized the “taking and throwing away” design methodology and selected only critical design elements—the gayageum and the player, which are essential elements in the form design of Gayegeum 3.0—and removed all other unnecessary elements (figure 6.5.3.C).

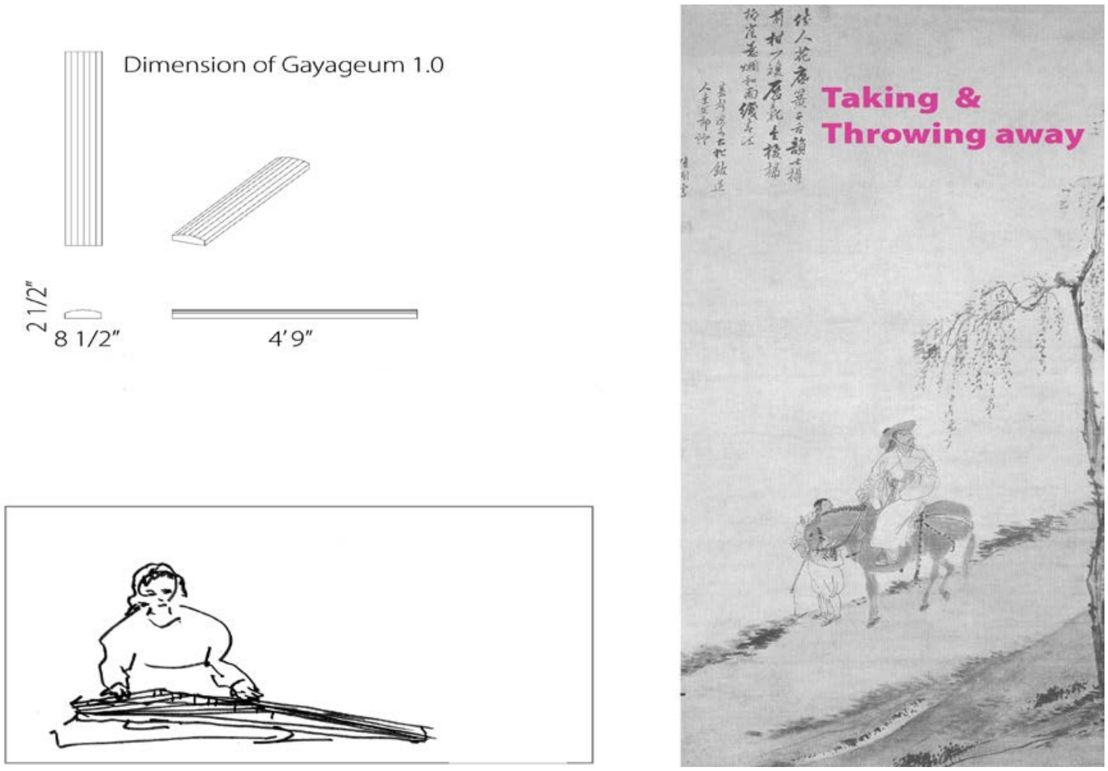



Figure 6.5.3.C Dimension of Gayageum 1.0 (top left); design element from *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (right); sketch created by utilizing the design element of composition referred to as taking and throwing away (bottom left)

Fourth, I drew a diagram that represents the depiction of strength and extended the longitudinal of gayageum by six inches. The increased length not only mimics the sense of movement of the linear shape, but also functions as a container for the vibration which creates the sound of the instrument (figure 6.5.3.D).

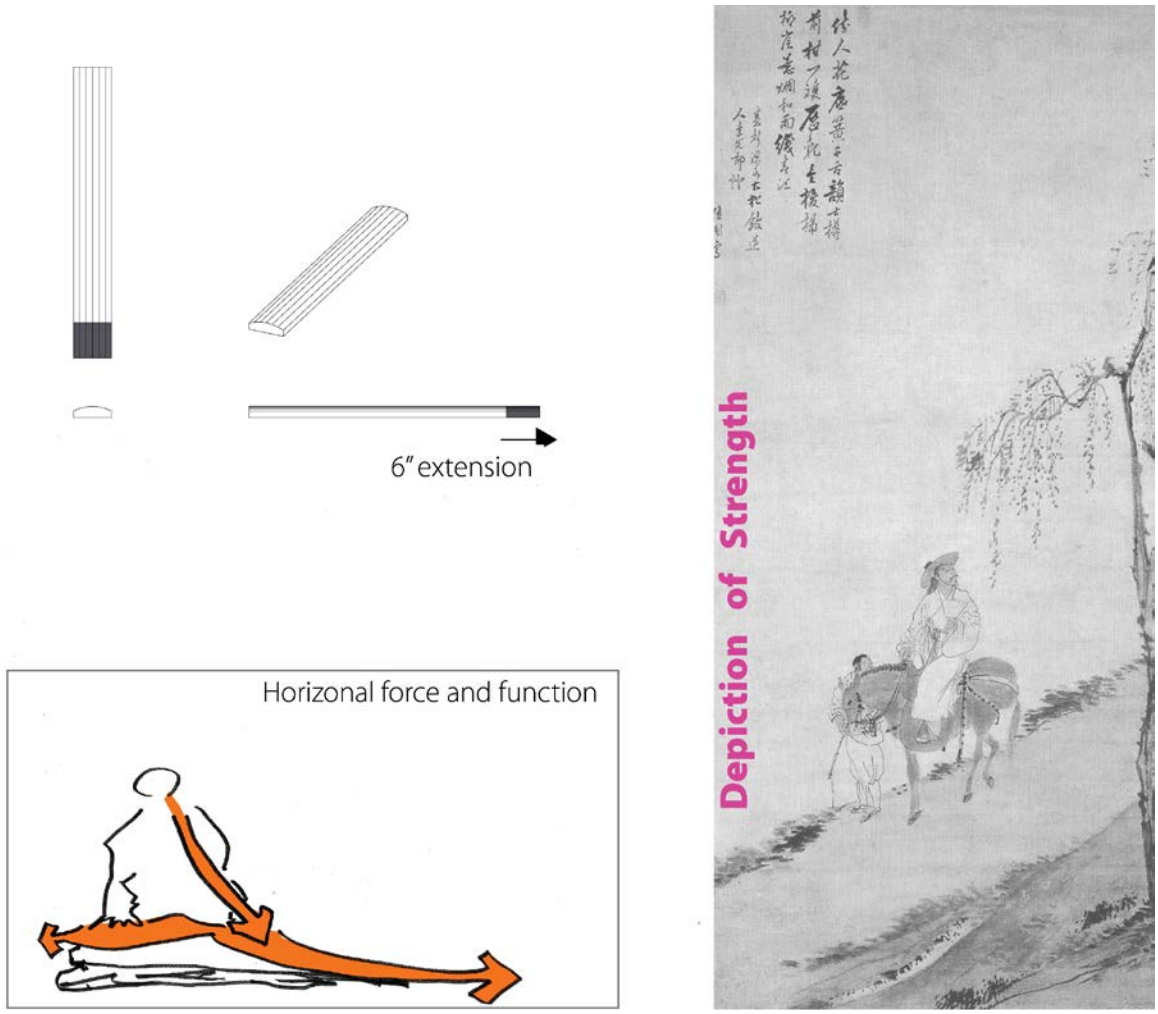



Figure 6.5.3.D 6" extension to the longitudinal of gayageum (top left); *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (right); sketch by adopting the design element of composition which is defined as depiction of strength (bottom left)

Fifth, I draw a diagram that describes an interconnection of the gayageum. The height of the gayageum is increased from two inches thick to four inches thick to give enough space to increase the resonance since the material of gayageum is paper. Then, I taper edges all around to create the perception that the thickness is equal to that of traditional gayageum. This is the harmony between the function and the aesthetics (figure 6.5.3.E).

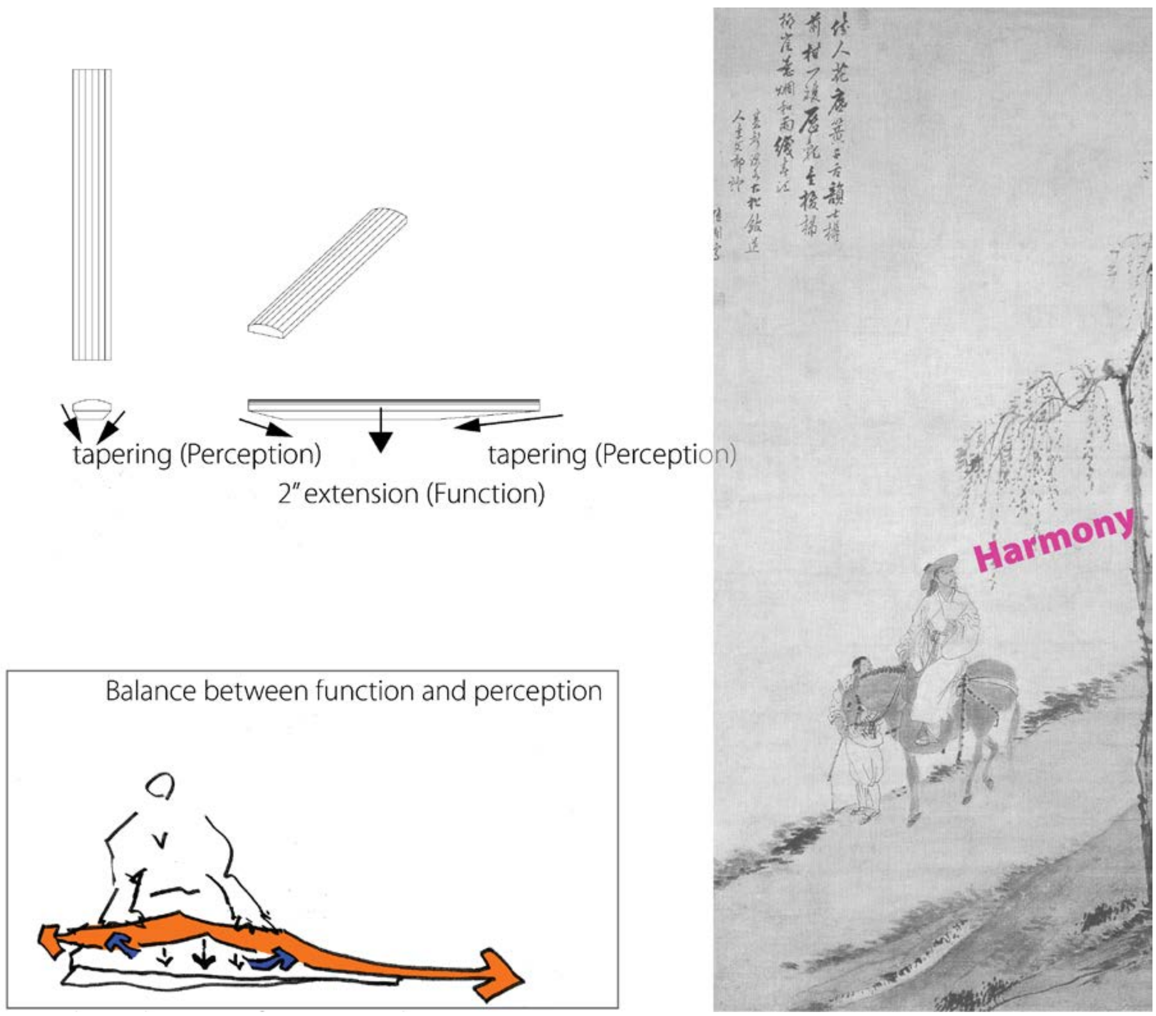



Figure 6.5.3.E 2" extension to the height of gayageum (top left); *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (right)/ sketch by adopting the design element of composition which is defined as harmony (bottom left)

The sixth step was adding some sound holes on the surface of the gayageum after adjusting the size and form of the gayageum. The small sound holes and the emptiness at the background represent the affinity between large space and small space (figure 6.5.3.F).

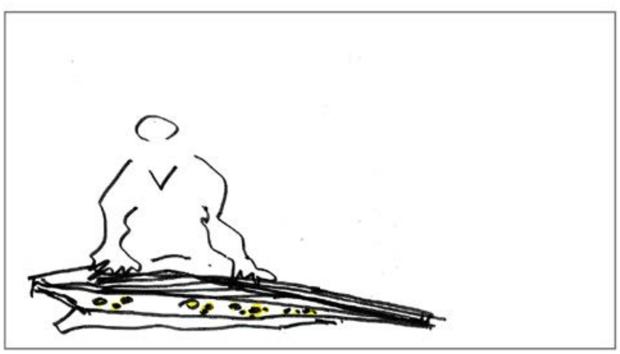



Figure 6.5.3.F Sketch by adopting the design element of composition which is defined as large space and small space (left); *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (right)

Last, I add the effect of looseness and density to enhance the experience of rhythm and tempo at the space by controlling the location of sound holes (figure 6.5.3.G).


Figure 6.5.3.G Sketch by adopting the design element of composition which is defined as loose and dense (left); *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (right)

## 6.6 Structure and Pattern

### 6.6.1 Structure and Pattern Design Framework

I set up the design framework for the structure and pattern design. The framework is designed to create three-dimensional paper structures and assemble together to make a linear shaped instrument body. To create the three-dimensional paper structure, I adopted the folding tectonic as explained in chapter 4. 3D Voronoi diagram is the one of the most appropriate approaches to make the three dimensional paper structure that should be bear the tension, compression, and shear stress. To define and adjust the 3D Voronoi geometry and its pattern, I utilize the composition of Korean painting as I do in the form design framework.

### 6.6.2 Voronoi Diagrams

The concept of a Voronoi diagram stems from a simple geometric concept. A Voronoi diagram is the collection of borders of points which are distributed evenly. Though the idea of a Voronoi diagram first came about roughly a century ago, its central concept has been widely adopted thanks to its practicality and constructive efficiency. It is very useful for explaining the phenomena of natural and structural space. Some recent examples of the adoption of the Voronoi diagram is its use in satellite navigation, tracking wildlife in its natural habitats, urban planning, and architecture.

A Voronoi diagram is a method of separating space into several regions. The diagram below represents how the Voronoi diagram is generated: a) Take a set of points. b) Construct a bisector between one point and all the others. The bisector is halfway between two points at an angle perpendicular to a line that would connect the two points. c) The Voronoi cell is bounded by the intersection of these bisectors. Any intersection found to be on the far side of a bisecting line is ignored. d) Repeat for each point in the set. Voronoi diagram is generated. Voronoi diagram has a principal of equal distribution from each point (figure 6.6.2.A)[74]. Diane Souvaine referred, “Consider the following problem. To determine the route for its carriers, the U.S. Post Office must decide which of its local offices is closest to a given point. Voronoi diagrams can used to solve this problem and many others including Closest Pair, All Nearest Neighbors, Euclidian Minimum Spanning Tree, and Triangulation problems.”[75]

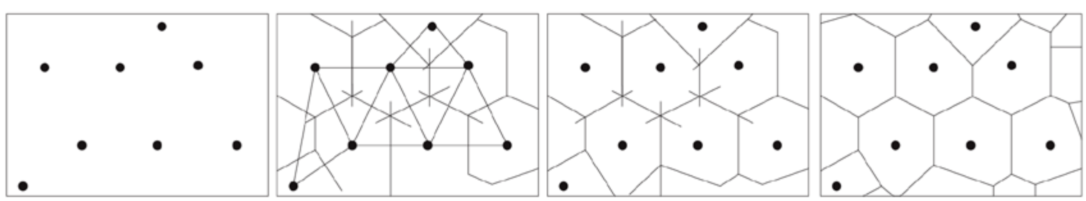



Figure 6.6.2.A Generative process of Voronoi diagram

74 Benjamin Aranda and Cecil Balmond, *Tooling* (New York: Princeton Architectural Press, 2006), 77.

75 “Voronio Diagrams,” Diane Souvaine, accessed October 20, 2013,

To define the shape of Voronoi unit, it is critical to lay out points in appropriate locations since the Voronoi geometry is generated from these points (figure 6.6.2.B).[76]

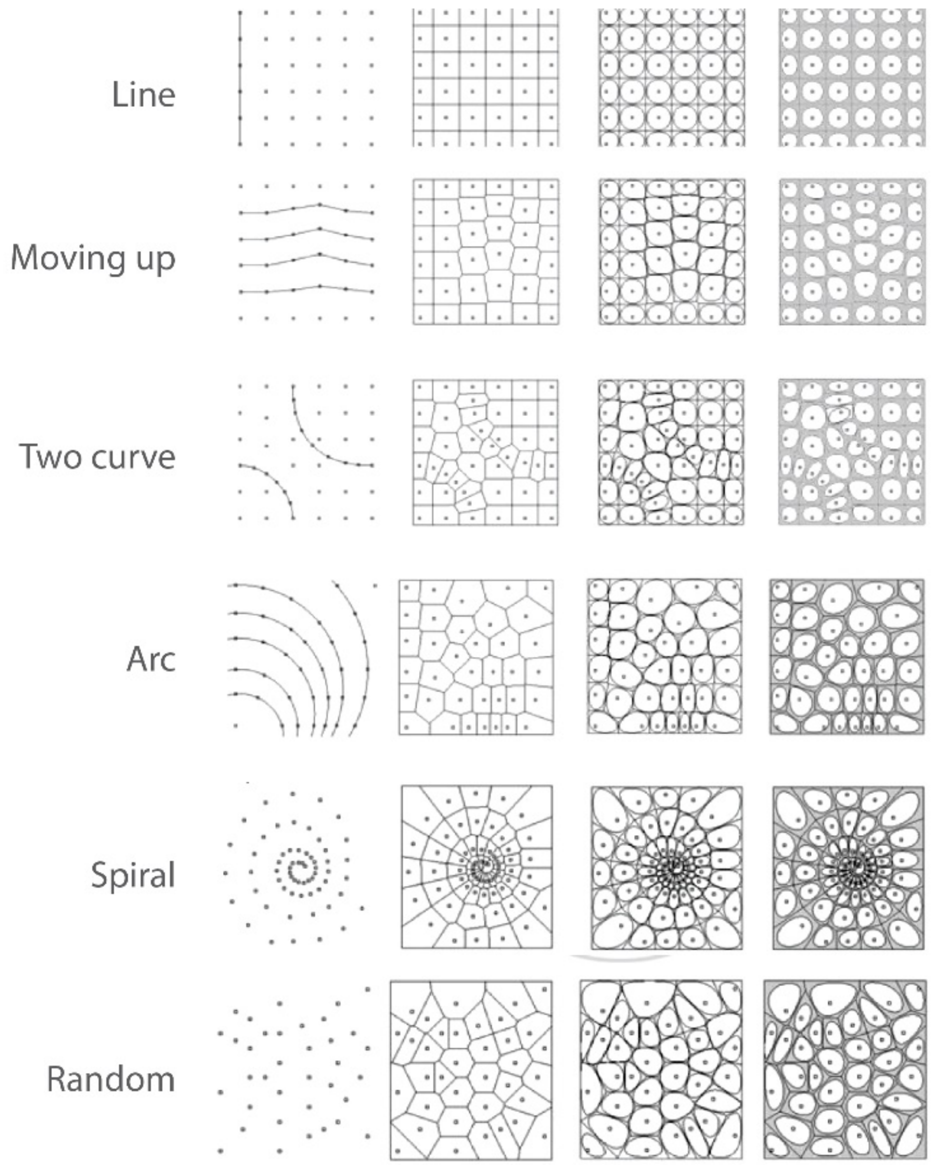



Figure 6.6.2.B Point distribution of Voronoi diagram

76 Jin Ho Park, “A Study of Morphological Design Possibilities Using the Voronoi Diagram” (Master thesis, Inha University, 2008)

### 6.6.3 Structure and Pattern Design Process

#### 6.6.3.A Points Selection

Taking and throwing away is to select critical elements and to remove unnecessary factors. I selected points from the key features such as twelve movable bridges, head bridges, loops, and cords of the traditional gayageum (figure 6.6.3.A).

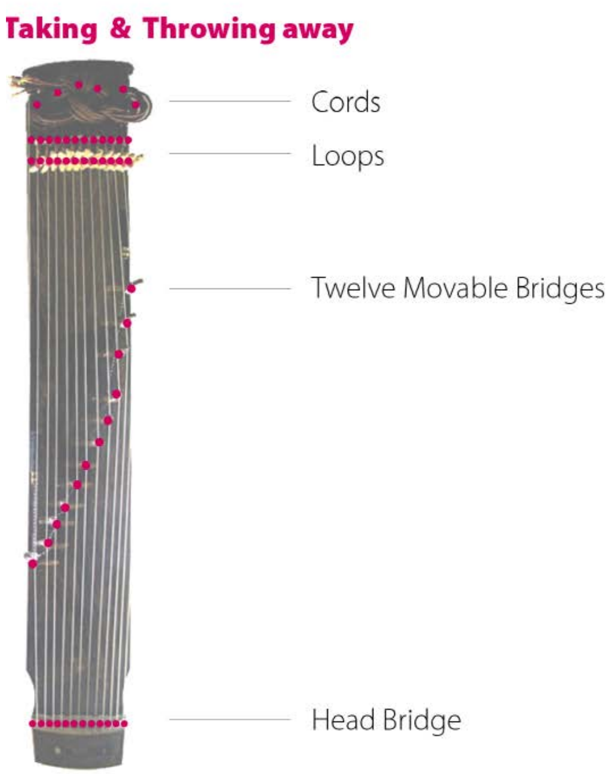




Figure 6.6.3.A Selection of points

### 6.6.3.B Distribution of Points

After selecting points from the key features, I insert points between other points in the twelve movable bridges, points in the loops, points in the twelve movable bridges and points in the head bridge by dividing the distance by eight. My decision to divide by eight was based on my assumption that the result would make a reasonable scale to be fabricated and structurally durable, and also allowing for spatial rhythm by creating a hierarchy of looseness and density (figure 6.6.3.B).

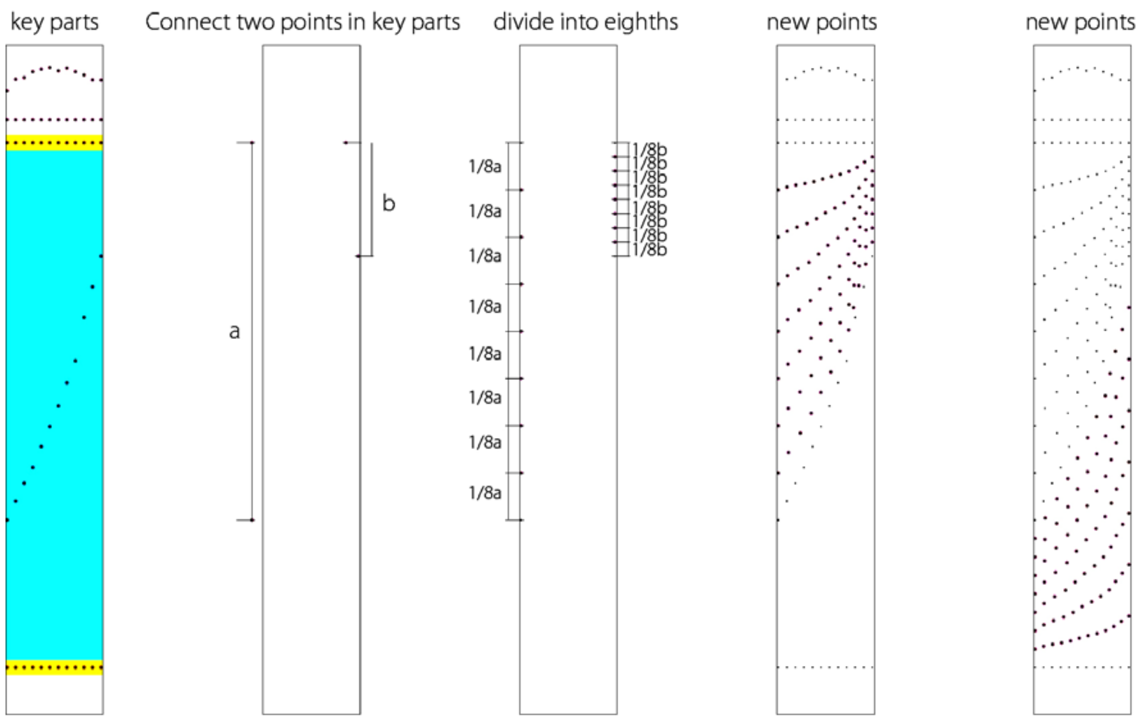



Figure 6.6.3.B Distribution of points

### 6.6.3.C from Points to 3D Voronoi Structure

After creating points on the floor plan, I figured out that the points were too spatially condensed, preventing me from making appropriately sized Voronoi units to be fabricated. Thus, I reduced the density by 50%. Then, I apply 3D Voronoi command in Rhino 3D to make 3D Voronoi units which harmonized well together. From there I simplified the top round surface of traditional gayageum (figure 6.6.3.C.a) by creating six flat surfaces that have slightly different angles (figure 6.6.3.C.b). These flattened surfaces are easily fabricated using laser cutter.

Figure 6.7.3.C.a Curved top surface of traditional gayageum

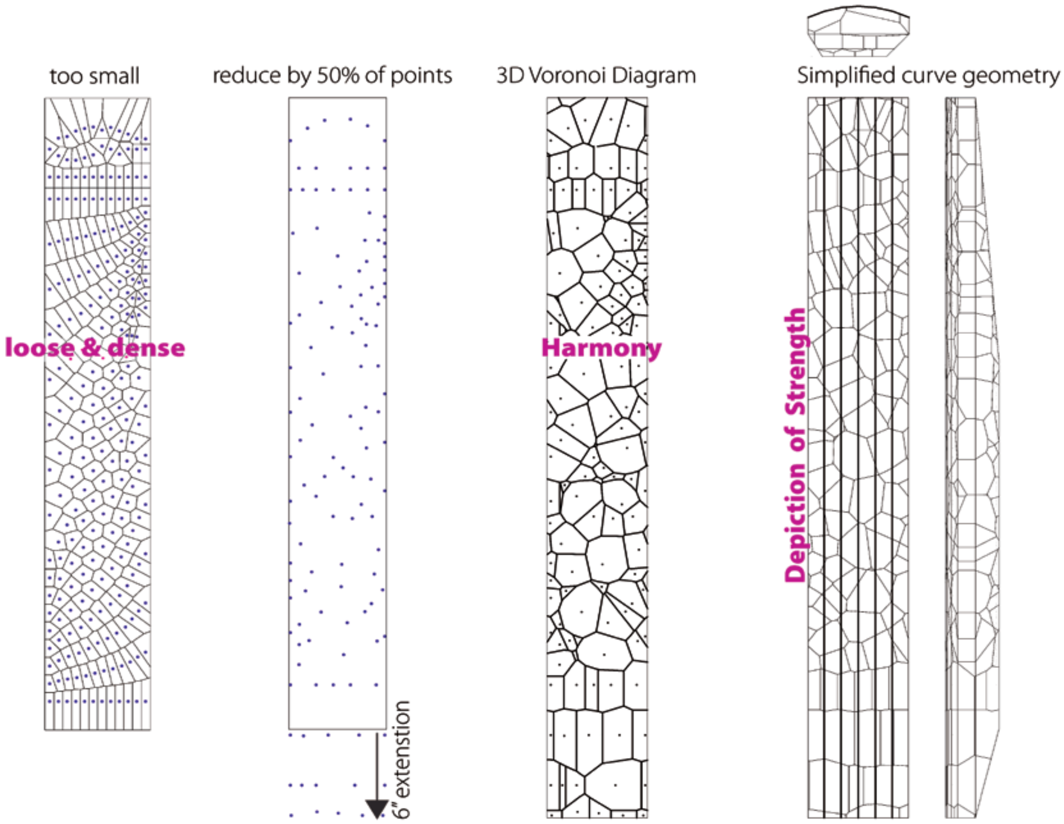
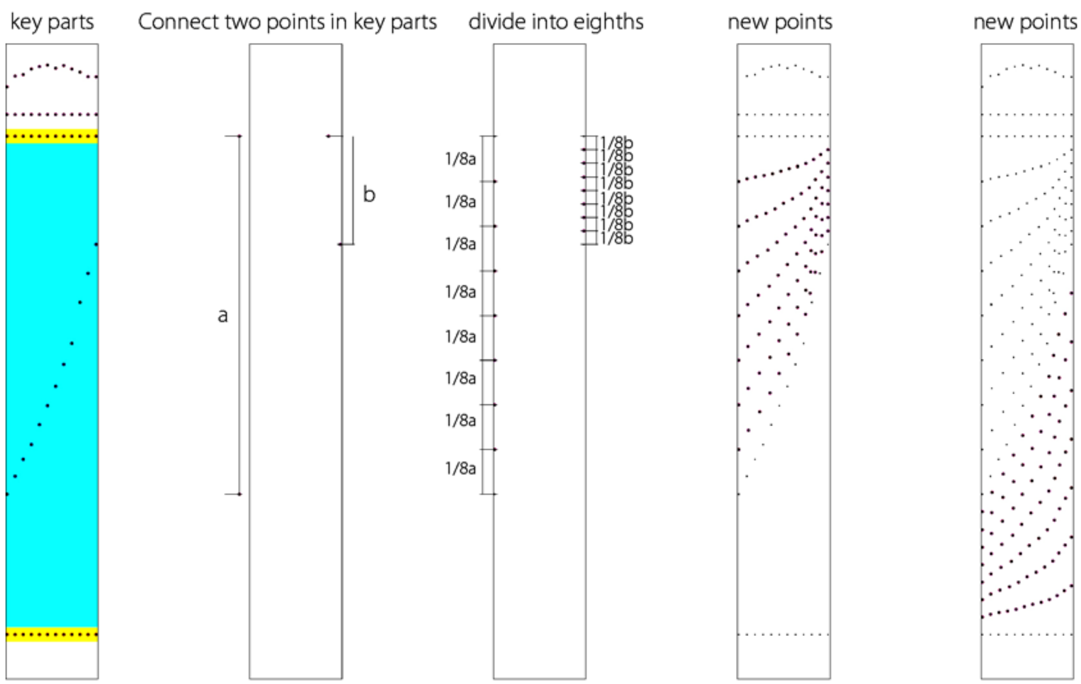



Figure 6.6.3.C.b The creation of 3D Voronoi structure which is developed from strategic point diagrams

### 6.6.3.D The Pattern of Sound Holes

On the surface of the gayageum, sound holes have small space by keeping a loose and dense rhythm. The small spaces have smoothly cohere with its surrounding space and air. Surfaces of each 3D Voronoi unit have sound holes, which have several radius by responding the corner geometry of each Voronoi cell. The definition of various radius can be easily done by using a computing power of Rhino Grasshopper. These parts that face outward have limited numbers of openings not only to enhance the vibration, but also to develop spatial composition between small space and large space (figure 6.6.3.D).



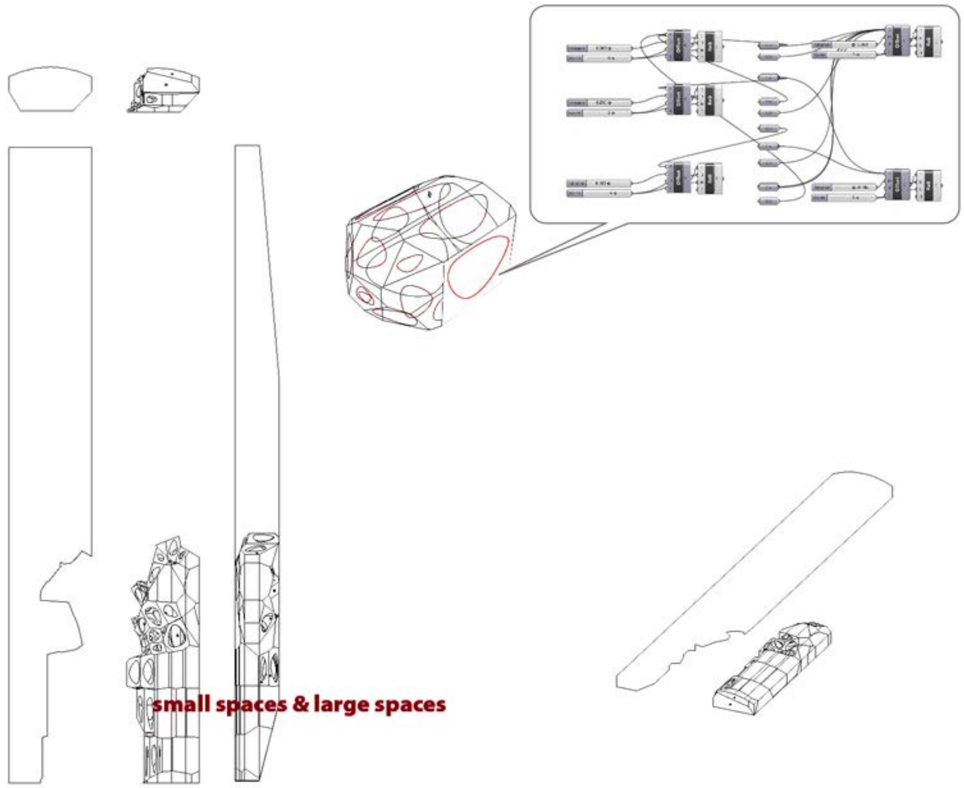



Figure 6.6.3.D Definition of various radius of sound holes operated by Rhino Grasshopper

## 6.7 Digital Fabrication

### 6.7.1 Laser Cut Layout

To fabricate 3D Voronoi cells, each unit is unrolled and laid out on the 2' x 3' sheet of Rhino Nest, which supports the nesting process on the sheets (Figure 6.7.1). Then, with the precision of a laser cutter, each unit is cut from the sheet.

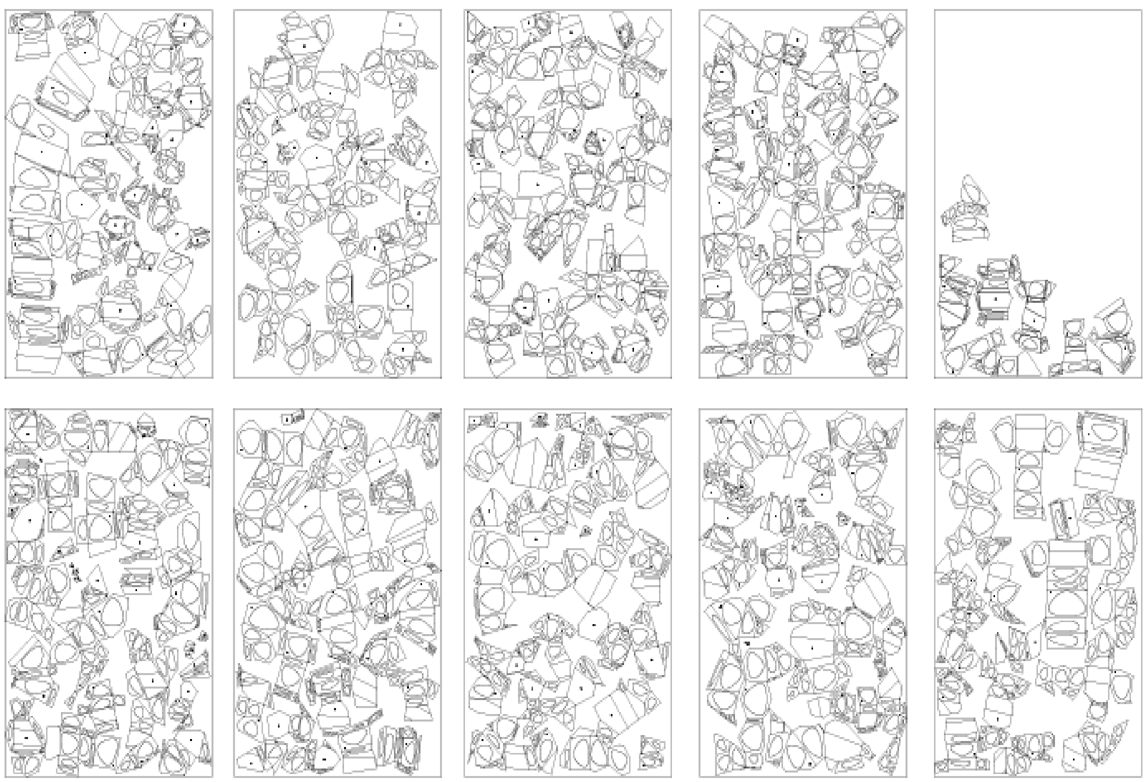


Figure 6.7.1 Laser cut layout on 2'x3'

### 6.7.2 Assembly Logistics

After laser cutting, each Voronoi unit is folded to construct a sturdy three-dimensional structure (figure 6.7.2.A). Although the material of each unit is paper, the folded paper is strong enough to bear a relatively significant amount of stress from various angles.

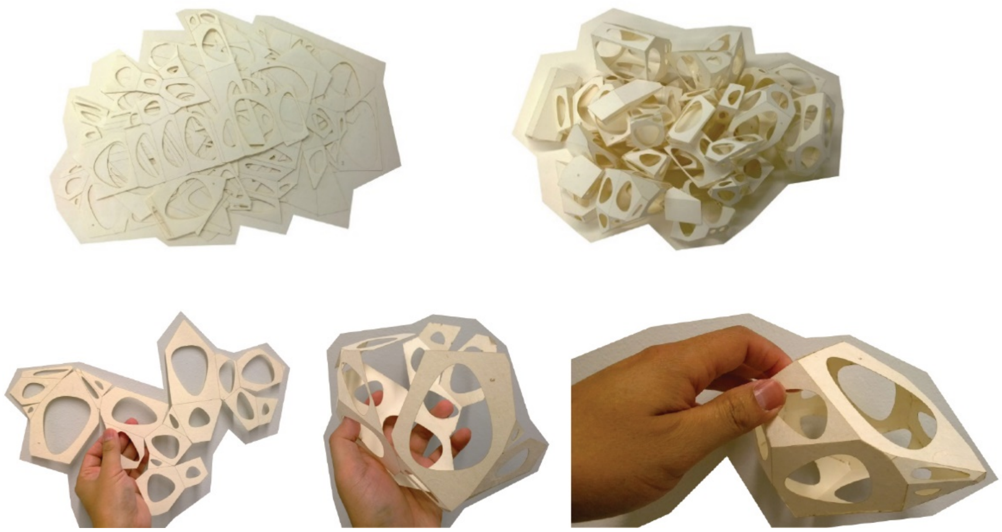


Figure 6.7.2.A Folding tectonic using Korean paper

Each 3D Voronoi cell has its own ID number which indicates its location in the assembly. After folding every Voronoi unit, they are arranged on a large sheet according to their given identification numbers (figure 6.7.2.B). In Rhino, for example, cell number 129 can be moved to the right side, then cell 129 can be attached to the instrument body.

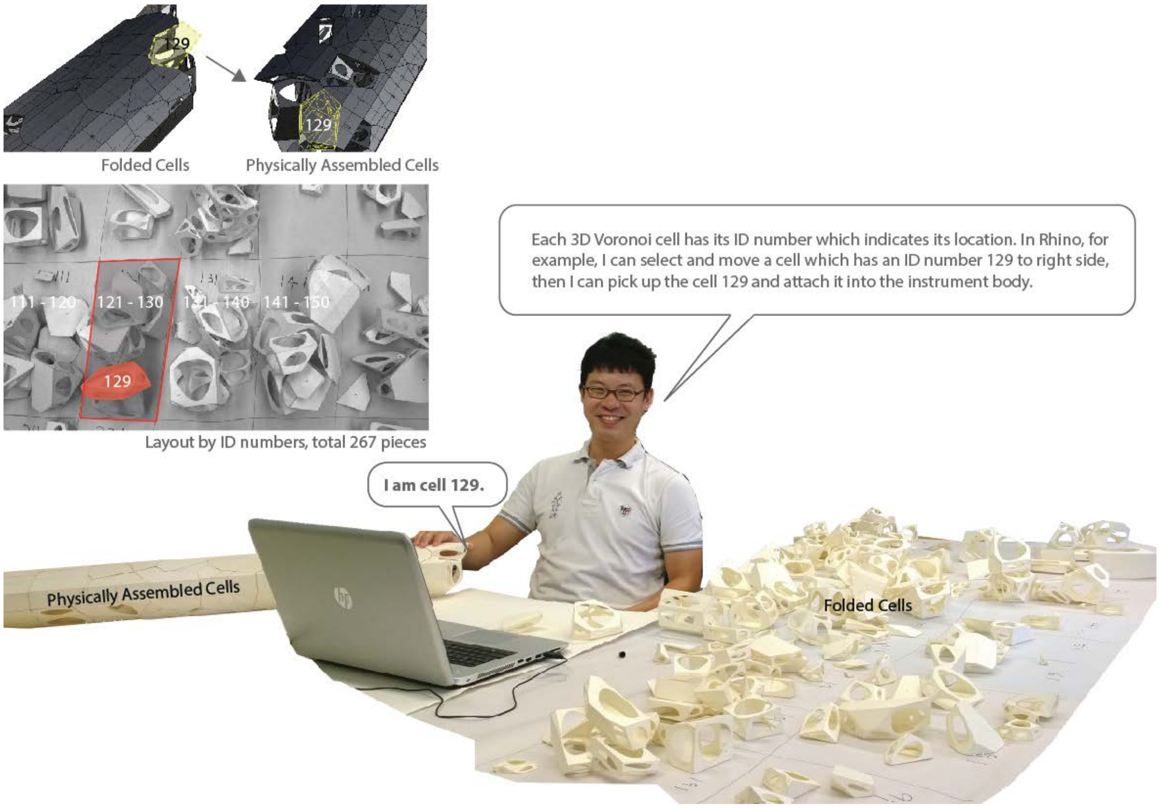



Figure 6.7.2.B Assembly logistics

Following the assembly logistics, 3D Voronoi units are assembled into a body by numerical sequence using paper glue. Each Voronoi unit has different angles which make the structure very durable against a given amount of compression, tension, and shear stress.

The goal of the assembly is to make a structural system which can serve as a space frame that resists tension, compression, and shear forces. Twelve head tuners are added at the end of the body. The head tuners allow the gayageum player to easily control the tensile strength of silk strings (figure 6.7.2.C).

Figure 6.7.2.C Assembly process

The 3D Voronoi space frame is compared in the photo below with a space frame from the Water Cube project in Bejing. The space frame is created by using the Weaire-Phelan structure which is an ideal procedure to mimic to create equal-sized bubbles.[77]

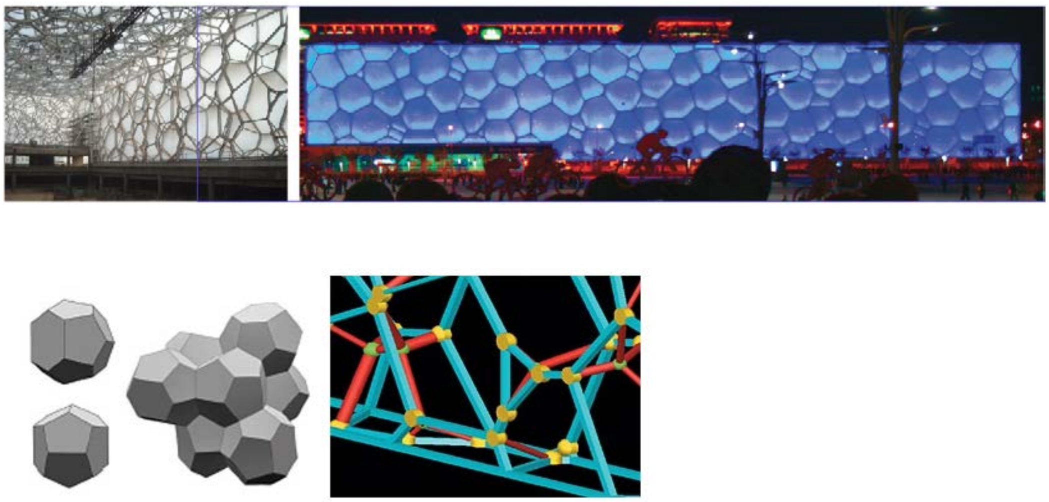


Figure 6.7.2.D Space frame using Weaire-Phelan structure, Water Cube, Beijing, 2008 (top), Structure of Weaire Phelan form (below left), CAD model of the structural system (below right)

Spraying an adequate amount of water on the surface tightens and strengthens the surface of paper (figure 6.7.2.E).

Figure 6.7.2.E Spraying water on the paper

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[77] "Engineering the water cube," Tristram Carfrae, accessed Nov 17, 2013, http://architectureau.com/articles/practice-23/

### 6.7.3 Surface Geometry

The geometry of elevations reflects the analysis of composition of Hong Do Kim's painting that was used as the example of composition in Chapter 6.5 "Form".


Figure 6.7.3.A *Listen a Song of Bird on the Horse* by Hong Do Kim, Korea, 18C (left); design elements analysis from the composition of the painting (right)

The form represents a depiction of strength by extending six inches horizontally and creates harmony by deepening two inches which is done by tapering all the edges. Tapering the edges makes the instrument appear less thick than it actually is. Slightly bent edge lines stress the depiction of strength (figure 6.7.3.B). The small and large sound holes represent a balance of large space and small space (figure 6.7.3.C). In addition, the density of sound holes evokes the sense of looseness and density. The 3D Voronoi assembly is easily readable at the surface pattern, which has various densities (figure 6.7.3.D).

Figure 6.7.3.B A depiction of strength & harmony

Figure 6.7.3.C Large space & small space

Figure 6.7.3.D Loose & dense of sound hole

### 6.8 Skin: The Layer of Spirit

The Gayageum 3.0 body is assembled out of three-fly handmade traditional Korean rice papers to bear tensional and compressional stress (figure 6.8.1).[78] The skin of Paper Mulberry is used in making this traditional Korean paper because of its durability, sturdiness, and longer fiber length. After the paper is dried and pressed, it becomes extremely durable and therefore is useful in countless ways (figure 6.8.2).[79]

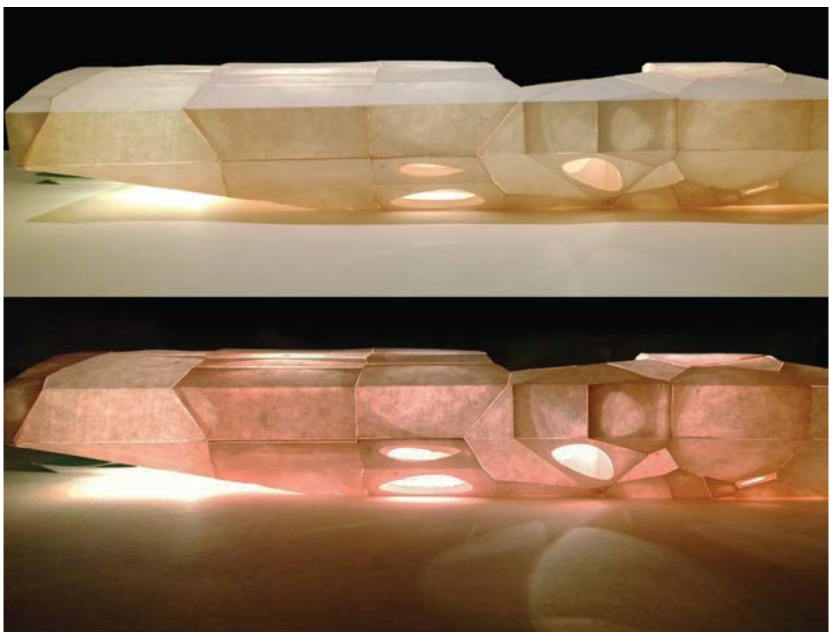

Figure 6.8.1 Materialization of the Gayageum 3.0 structure shown here with lit from within with an LED strip light

78 "Hanji Making Process," accessed Octoberober 21, 2013, http://www.wonju.go.kr/hb/TPSECT19/sub02_04_03

79 "Hanji Making Process," accessed Octoberober 21, 2013, http://www.wonju.go.kr/hb/TPSECT19/sub02_04_03


Figure 6.8.2 Hanji (Korean paper) making process: 1. Collecting materials, 2. Sorting, 3. Cooking the skin of Paper Mulberry, 4. Rinsing fibers with wate, 5. Beating the fibers to create a fibrous pulp, 6. Spread to desired thickness onto a board, 7. Pressed and again spread as desired into 'windows' to produce thin, large pieces of paper, 8. Left to sun dry

Recall the concept of a wrapping cloth as I discussed in chapter five. The wrapping cloth is a very common and central component of traditional Korean lifestyles (figure 6.8.3). Wrapping the Gayageum 3.0 with a thin traditional Korean rice paper, which is sturdy enough to endure the tensile stress as a result of its longer fiber length. This also makes the paper space frame more durable, but still allows sound to come through its porous boundaries (figure 6.8.4 and figure 6.8.5).

Figure 6.9.3 A wrapping cloth, Korea

Figure 6.9.4 Reinterpretation of traditional Korean rice paper as a wrapping skin

Figure 6.9.5 Wrapping Gayageum 3.0 using a thin traditional Korean rice paper

Soft shadows and natural sounds pass through the skin and structure of Gayageum 3.0 which not only illuminates its beautiful Korean origin, but also modifies the traditional sound, allowing the traditional gayageum instrument to find its place in modern music culture not only in Korea, but worldwide (figure 6.8.6).

Sound holes on the surface of Gayageum 3.0 are all enclosed by the Korean traditional rice paper, which means that it not only encourages the vibration of the instrument, but also creates a sensory sound that represents the spirit of Korea by emitting the vibrated sound through the rice paper (figure 6.8.7 and figure 6.8.8). It is a representation of my experience having lived in a traditional Korean house. Because the house was constructed of Korean paper, no matter where I was in the home, I could very clearly hear the sound of nature including wind, rain, and animals, Even when all the doors and windows were closed, I could still feel the warmth of natural light seeping through the traditional Korean rice paper.

Figure 6.8.6 Namchon House, Korea 18C (left); Korean paper lamp (middle and right)

Figure 6.8.7 Emit sound and light though traditional Korean rice paper

Figure 6.8.8 Emit sound and light though traditional Korean rice paper

### 6.9 Structural Adaptation

After finishing the assembly of 3D paper Voronoi cells, twelve head tuners and a nut and bridge are installed at the instrument body. Then, twelve silk strings are connected to the bridge and twelve head tuners (figure 6.10.1).

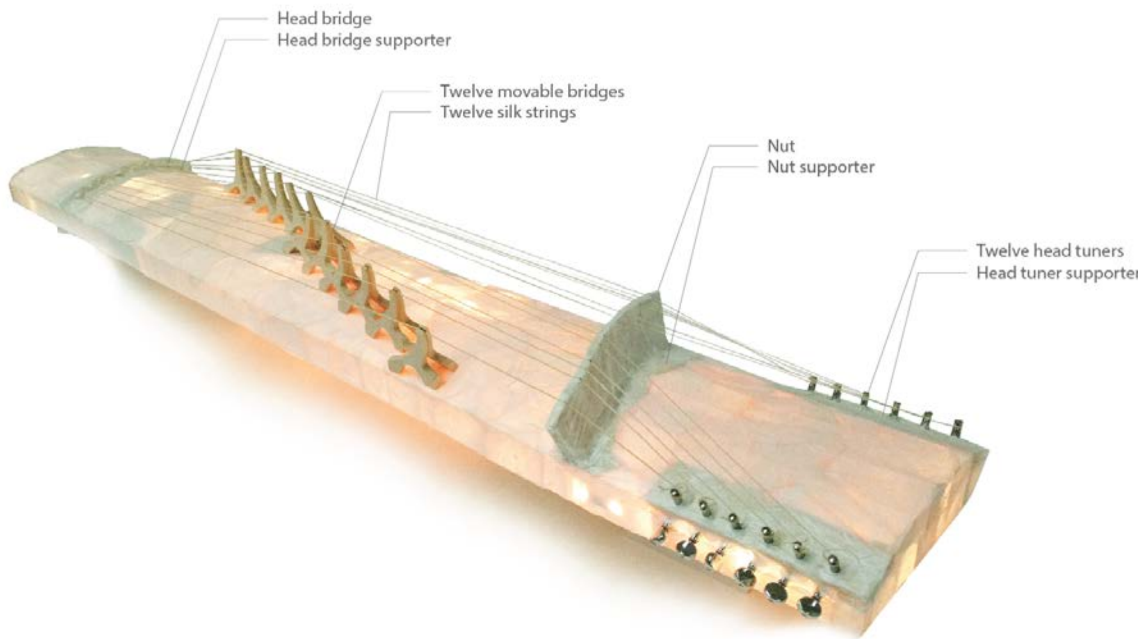


Figure 6.9 Parts of Gayageum 3.0

The tensile stress, however, is too strong to allow for structural balance of the paper structure. The stress easily bends both edges of the Gayageum 3.0 as can be seen in photo number four in figure 6.10.2. Upon being advised by my committee members to do so, I add counter tension strings at the bottom of the instrument which creates a structural balance as can be seen in photo number five in figure 6.9.2 and figure 6.9.3.


Figure 6.9.2 1. Traditional Sanjo Gayageum, 2. Assembly of Korean paper 3D Voronoi cells, 3. Surface geometry, 4. Applying tensile stress using silk strings at the top, 5. Applying counter tensile stress at the bottom

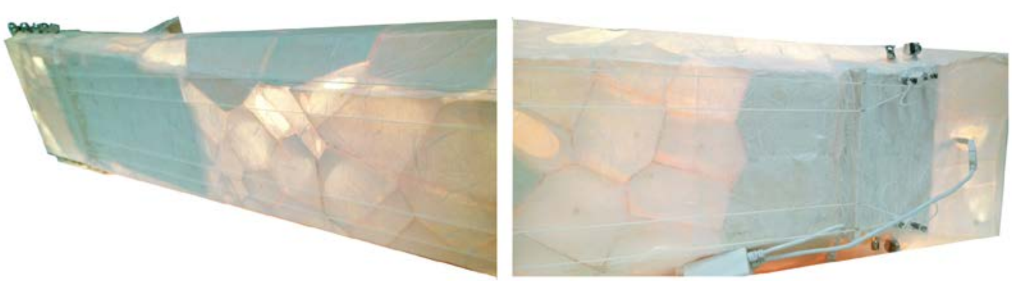

Figure 6.9.3 Counter tension strings at the bottom of instrument

### 6.10 Movable Bridges

Twelve movable bridges are a key feature of Gayageum. They have to be easily moved so that the individual playing the instrument can control the tone of the sound. The use of digital technology in the making of Gayageum 3.0 has made the moderninzation of this traditional instrument possible(figure 6.10.1).

Figure 6.10.1Movable bridges in traditional Sanjo Gayageum (left); movable bridges in Gayageum 3.0 (right)

The design of movable bridges is inspired by the composition of Korean painting titled*Korean Wrestling*by Hong Do Kim in the eighteenth centry. There are two people who are playing Korean wrestling in the center of the painting. Their clinch creates a dynamic form that is surrounded by a static oval form. The key element which enhances the energetic gesture is their location of foot. I used the placement of each wrestler's foot as a point mark, and then outlined a shape by connecting the three point marks of the wrestlers' foot placement As a result, the form reflects the experience of traditional Korean sports by associating the moment of play. Then, I minimized the volume of Maple solid wood to concisely deliver the vibration from the silk string to the instrument body. Each bridge piece is composed of two parts which is symbolic of two people who are partaking of Korean wrestling (figure 6.10.2).


Figure 6.10.2 Korean Wrestling, Hong Do Kim, 18C (left); Design concept of movable bridges (right)

Each piece of the bridges is cut by a CNC router (figure 6.10.3), then trimmed by various machines including an electric sander and table saw (figure 6.10.4). As a result, the geometry of the final product is very similar to the form of the concept sketch (figure 6.10.5).

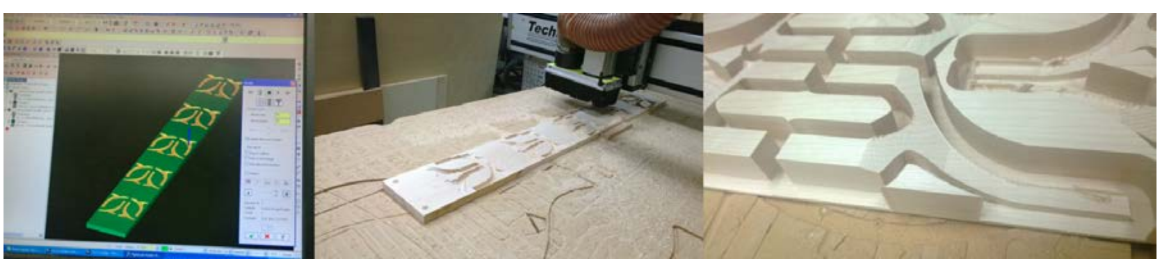

Figure 6.10.3 CNC cut process

Figure 6.10.4 Bridge trim after CNC cut

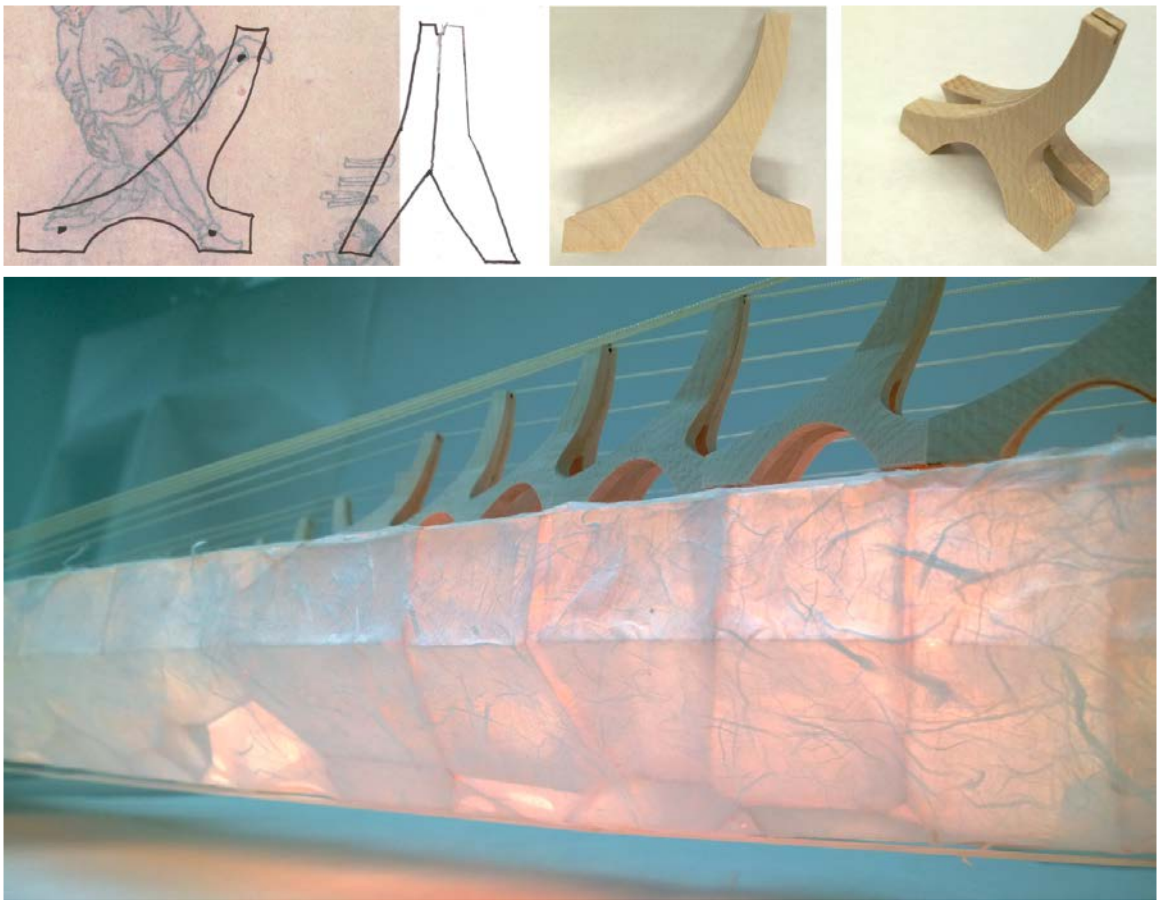

Figure 6.10.5 Concept sketch of movable bridge (top left); Digital fabricated movable bridge (top right and bottom)

## 6.11 Sound Test: Sound Waveform of Reverberation

To check the sound quality, I fabricate a particular part, which has approximately 20% volume in the middle. The black portion of the diagram below illustrates the mock-up (figure 6.11.1).

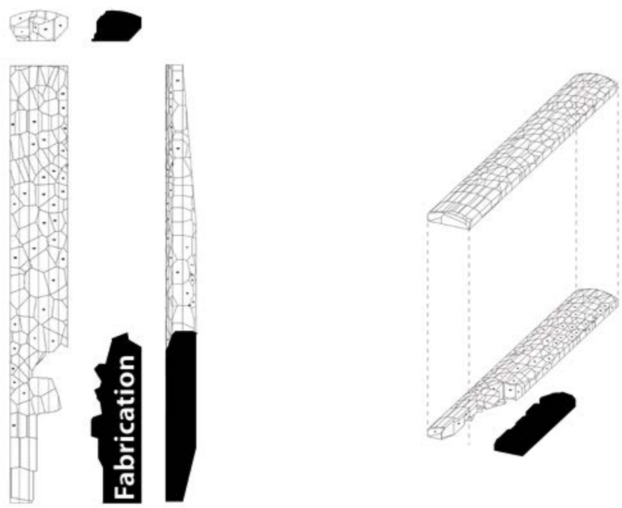


Figure 6.11.1 Digital fabrication sound test mock-up

After finishing assembly, I spray on enough water to Gayageum 3.0 and slowly dry it. As the paper slowly dries, the surface tightens.

Then, I prepare a wooden structure that bears the tension stress of a gayageum string. A guitar head mechanism is installed at the end of the wooden structure to tightly fasten the gayageum string. Finally, I place the Gayageum 3.0 model, which is enclosed by paper to block most of its holes, within the wooden structure, and connect a wooden bridge and a silk string as there would be on a traditional gayageum (figure 6.11.2).

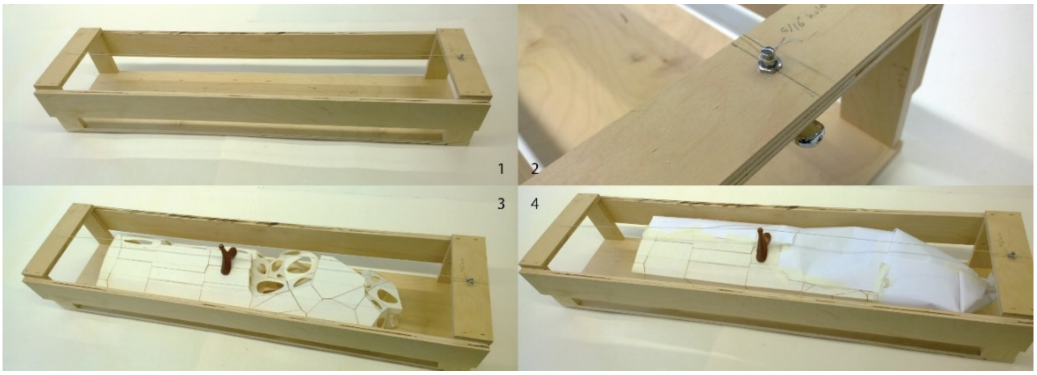


Figure 6.11.2 1. A structure for gayageum string installation 2. Installing guitar head mechanism to fasten gayageum string 3. Placing Gayageum 3.0 and connecting to a bridge with silk string 4. Enclosing holes with regular copy paper and checking sound

The experiment is executed during 18s at the same place with the same string, bridge, and recorder. After the sound recording, it is played using Adobe Premiere software. The graph below shows how Gayageum 3.0 and a traditional Gayageum have different time spans of reverberation(figure 6.11.3). As shown by doing this test, Gayageum 3.0 mock-up has a much shorter reverberation time span compared to the traditional Gaygeum.

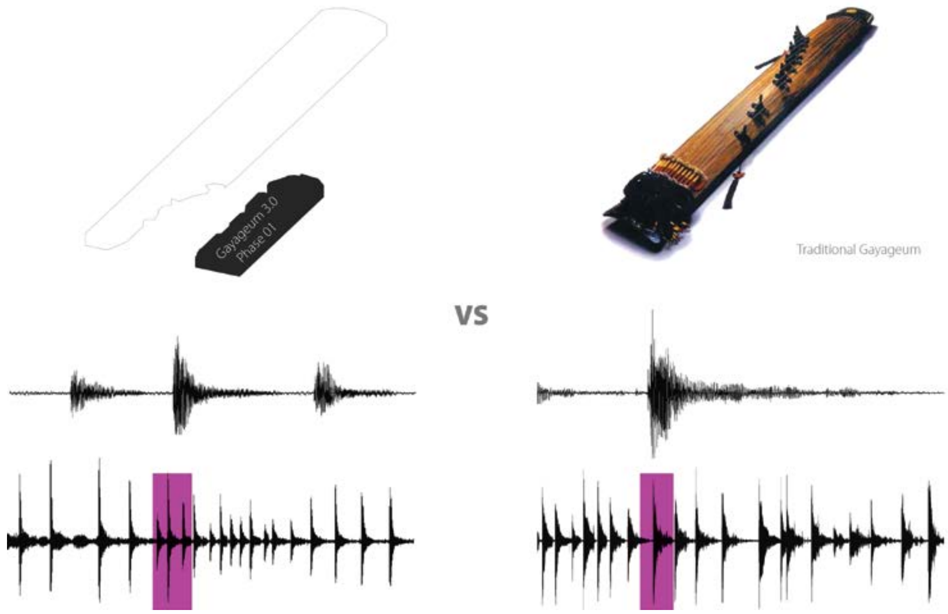


Figure 6.11.3 Sound wave reverberation form Gayageum mock-up with regular copy paper (left);Sound wave reverberation of traditional Gayageum (right)

The results of the sound test were disappointing as they proved that the reverberation time of the paper is so much shorter than to the traditional gayageum. The sounds of the two versions of the gayageum were incomparable

I decided to execute some experiments to further test the sound reverberation of Gayageum 3.0. I wrap the holes of Gayageum 3.0 mock-up using four different materials including regular print paper, Korean paper, corn oil painted Korean paper, and transparent lacquer painted Korean paper (figure 6.11.4).

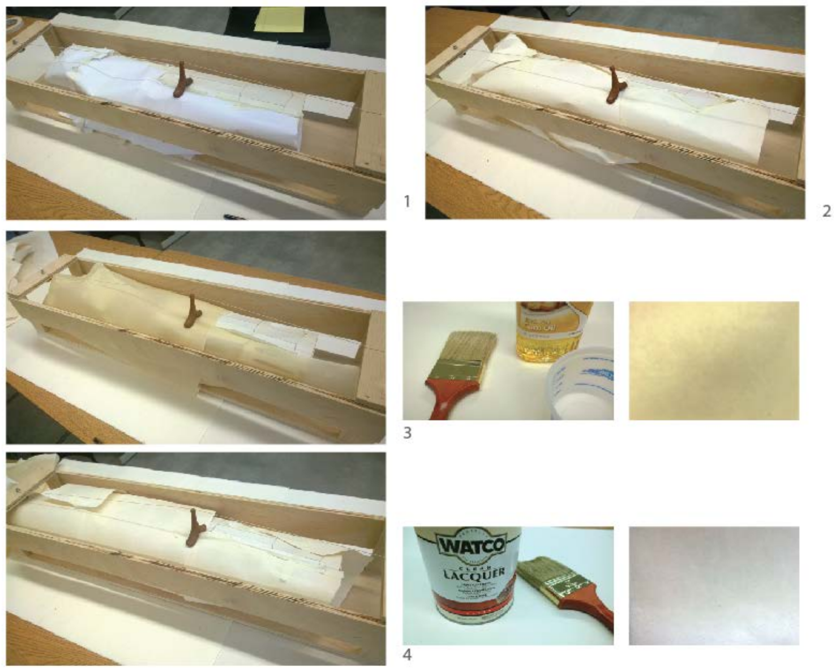


Figure 6.11.4 1. Wrapping holes with a regular letter paper, 2. Wrapping holes with Korean rice paper, 3. Wrapping holes with a corn oil painted Korean rice paper, 4. Wrapping holes with a transparent lacquer painted Korean rice paper

As the result of four different experiments, I was able to determine that the transparent lacquer sprayed inside and wrapped with the transparent lacquer painted Korean paper has the longest reverberation time (figure 6.11.5). This proves that the transparent lacquer is able to reflect and amplify the sound adequately.

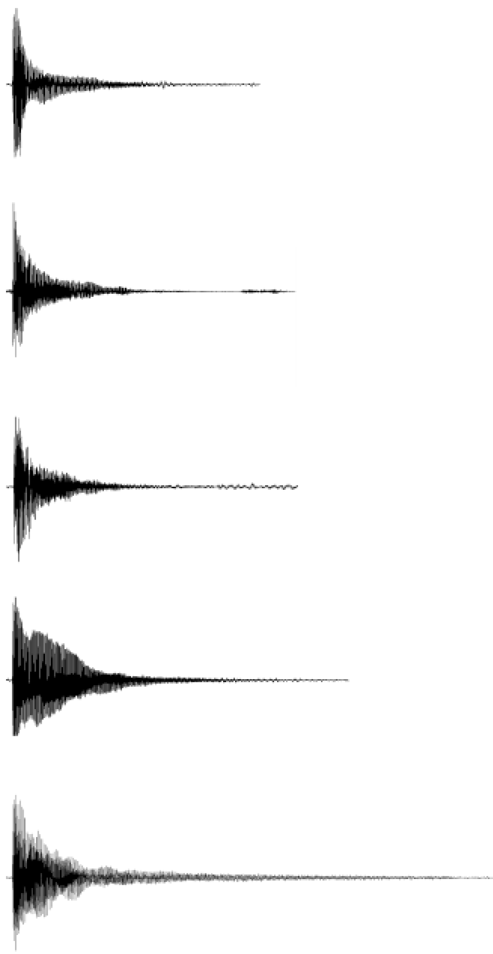

Figure 6.11.5 The respective reverberation times of sound produced by Gayageum 3.0 when wrapped in the following materials: regular paper, Korean rice paper, Corn oil painted Korean rice paper, transparent lacquer painted Korean rice paper. The last reverberation is that of the traditional gayageum (from top)

Then, I compared the reverberation time of the transparent lacquer sprayed and painted Gayageum 3.0 mock-up with traditional gayaguem and discovered that the reverberation time is still much shorter than the traditional gayaguem, and, the tone is much higher than the traditional gayageum (6.11.6).

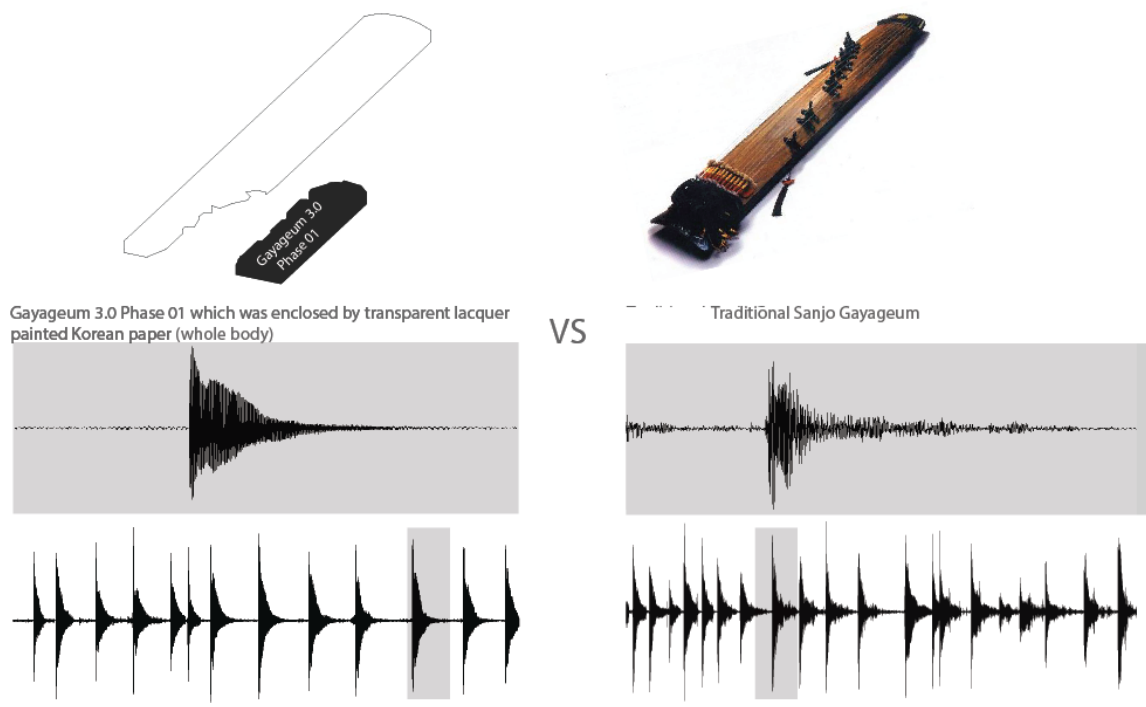


Figure 6.11.6 Reverberation time of Gayageum 3.0 mock-up which was enclosed by transparent lacquer painted Korean rice paper (left); Reverberation time of traditional gayageum (right)

After the final model of Gayageum 3.0, I test the reverberation time and compare it with that of the traditional gayageum. The experiment is, again, executed during 18 seconds at the same place with a same string, bridge, and recorder. As a result of the test, Gayageum 3.0 still has shorter time of reverberation than the traditional gayageum (figure 6.11.7).

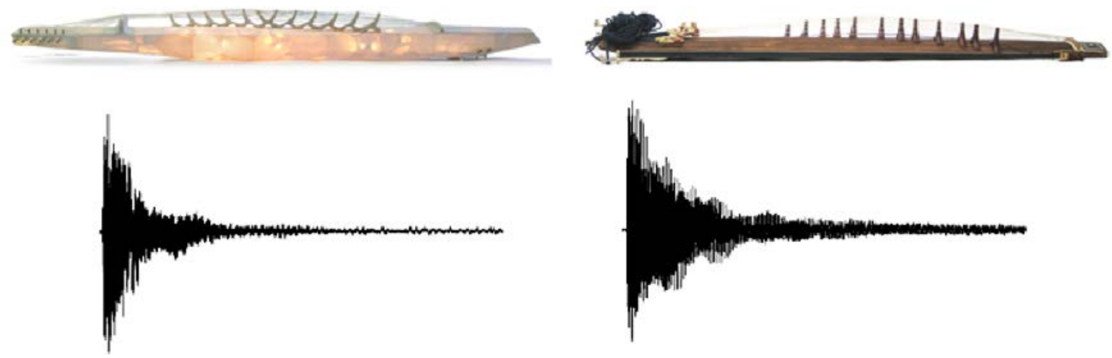

Figure 6.11.7 Reverberation time of Gayageum 3.0 (left), reverberation time of traditional gayageum (right)

### 6.12 Gayageum 3.0 Play

I test the gayageum with a the help of an actual gayageum player. Hae-In Lee, who played Gayageum 3.0, says that the tension is not strong enough to make large sound. There is a limit for the structural strength because of the weak property of paper in compressional stress. If there is tension at the top and bottom, the structure bears a significant amount of compressional stress, causing unnecessary squeezing of some of the Voronoi cells. This decreases the volume, making its volume capacity much lower than the traditional Sanjo Gayageum which has a wooden structure. Hae-in Lee also mentions that the height of the head bridge is slightly higher than the traditional one, making playing Gayageum 3.0 more challenging (figure 6.12).

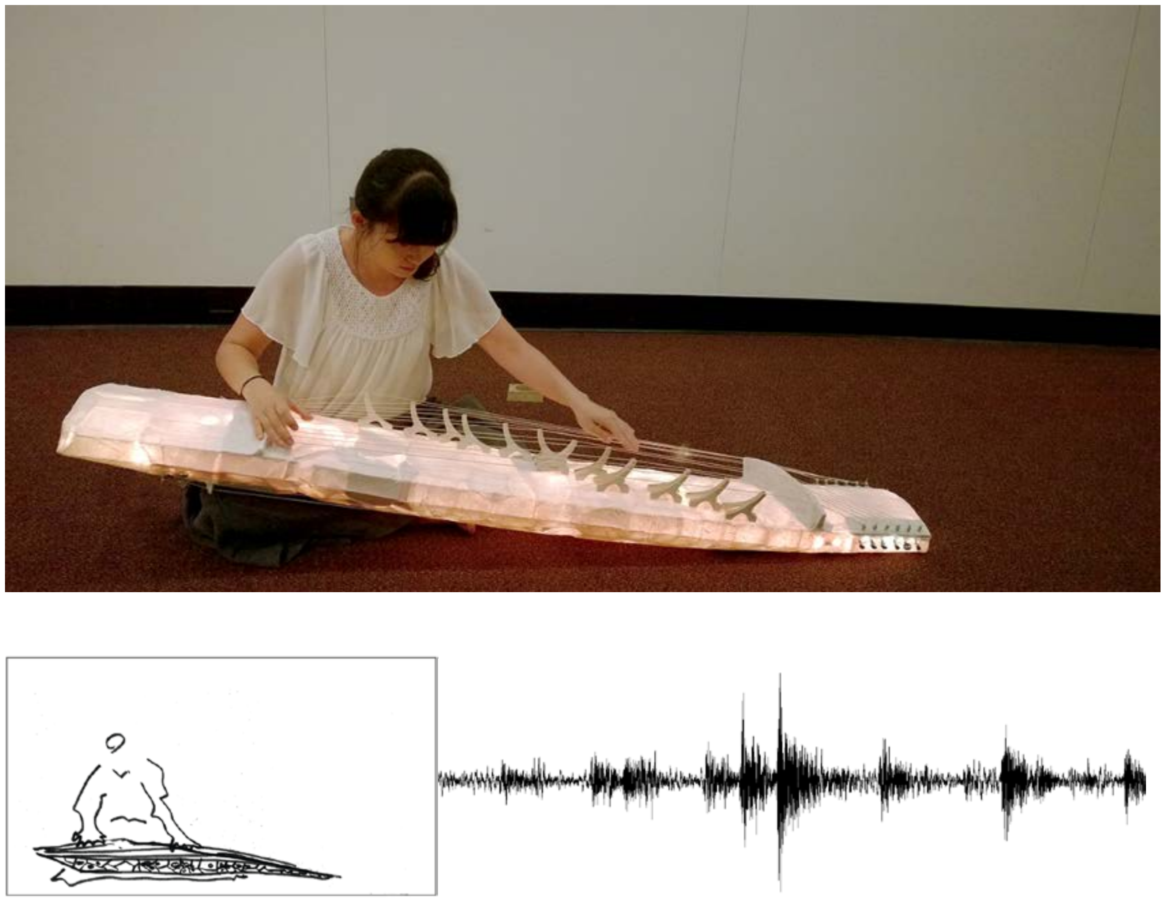

Figure 6.12 Gayageum 3.0 play by Hae-In Lee (top), Concept sketch of Gayageum 3.0 (bottom left); reverberation time sound wave of Gayageum 3.0 (bottom right)

## 7. Conclusion: The Tradition, Gayageum 3.0 and the Future

Gayageum 3.0 is an experiment to emphasize the localization of emerging digital tectonics to architectural students and professionals who have used digital fabrication. By reinterpreting a local, traditional string instrument, the gayageum. I created Gayageum 3.0 which integrates Korean tradition and global digital technologies through architectural components such as structure, surface geometry, materiality, space, sound, spirit, and assembly logistics.

Though the primary challenge prevented me from controlling the quality of sound, I tried many experiments to increase the reverberation time of Gayageum 3.0, but it is still significantly shorter than the traditional gayageum because of the material property of paper. In the future, I believe that the innovations in structural systems and digital tectonics will enable control sound quality which would allow modified traditional instruments to play not only traditional Korean music and Western music, but modernized multi-cultural music as well by reinterpreting tradition to integrate tradition and contemporary lifestyle.

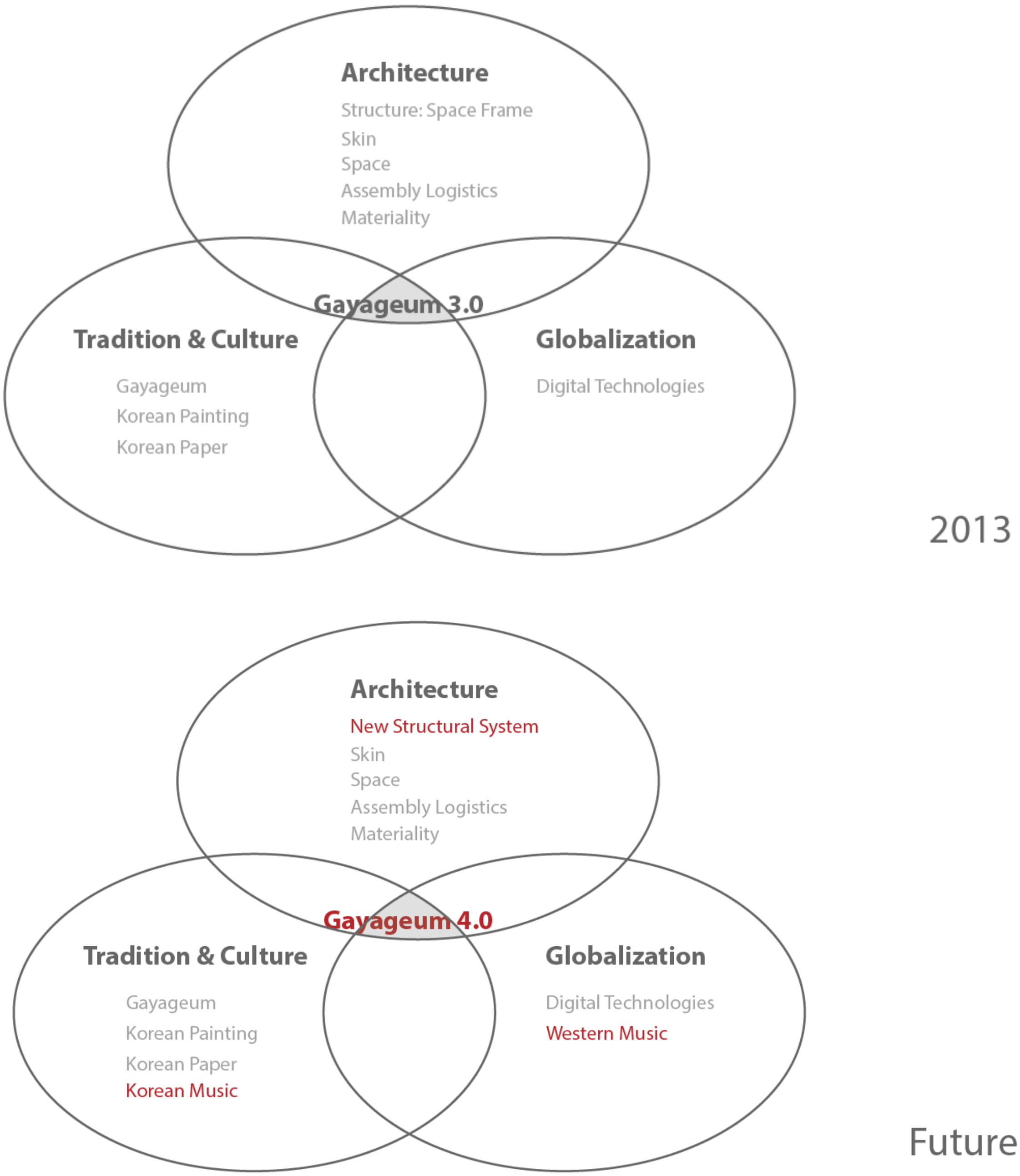


Figure 7 Gayageum 3.0 and the future

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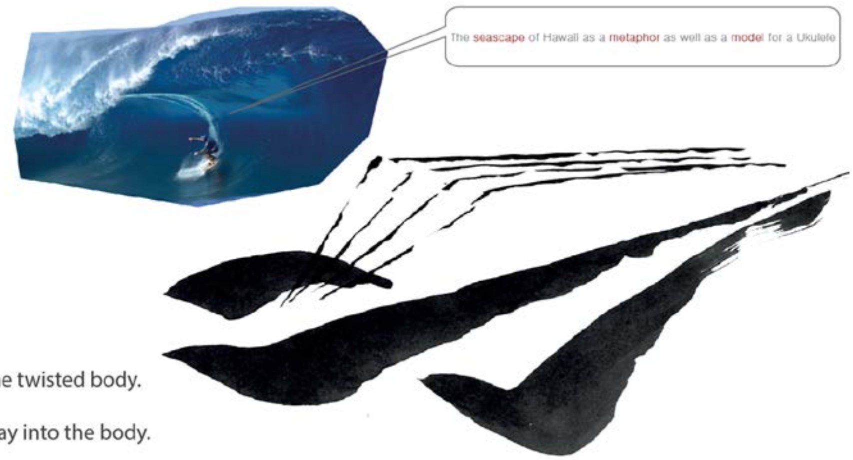
# APPENDIX A: PARAMETRIC UKULELE: REINTERPRETATION OF TRADITIONAL UKULELE USING TESSELLATION TECTONICS

## A.1 Abstraction of Nature

I made an experiment of parametric string instrument at the Digital Fabrication class which was taught by Lance Walters who is my D.ARCH Committee member. In this experiment I would like to explore the pros of the assembly logistics of the digital design fabrication by simplifying the geometry of non-linear forms through the tessellation tectonics that I researched in chapter four. The experiment will be contributed to the digital design fabrication of non-linear forms by reducing construction costs and time, and by enhancing workability. I am going to use the assembly logistics of the ukulele structure to investigate this idea.

If the digital assembly logistics is applied to the construction of the ukulele, then the complexity of the assembly and construction might be reduced regardless of the level of complexity in the initial “design” phase.

As an experiment that reflects Hawaiian spirit, I adopted the image of wave at the beach of Hawaii and designed an abstract form of ukulele by drawing inspiration from a poem (figure A.1.1).




Waves form a twisted body.

The floating wires flow along the twisted body.

The rhythm of wires soaks its way into the body.

The emptiness of the inner body is filled with the delight sound.

A sense of memory vibrates within the tranquility.

Figure A.1.1 Concept sketch and poem

Then, I created a simplified geometric form by dividing the non-linear surface of the ukulele body into 5x7 divisions (totaling thirty five pieces) (figure A.1.2). In the process, I added two connectors in between two different notched pieces to connect these two parts together (figure A.1.3). Parametric data through Rhino Grasshopper script is applied in the digital model, so the applied data can automatically follow the change of the original non-linear surface's form and angle (figure A.1.4).

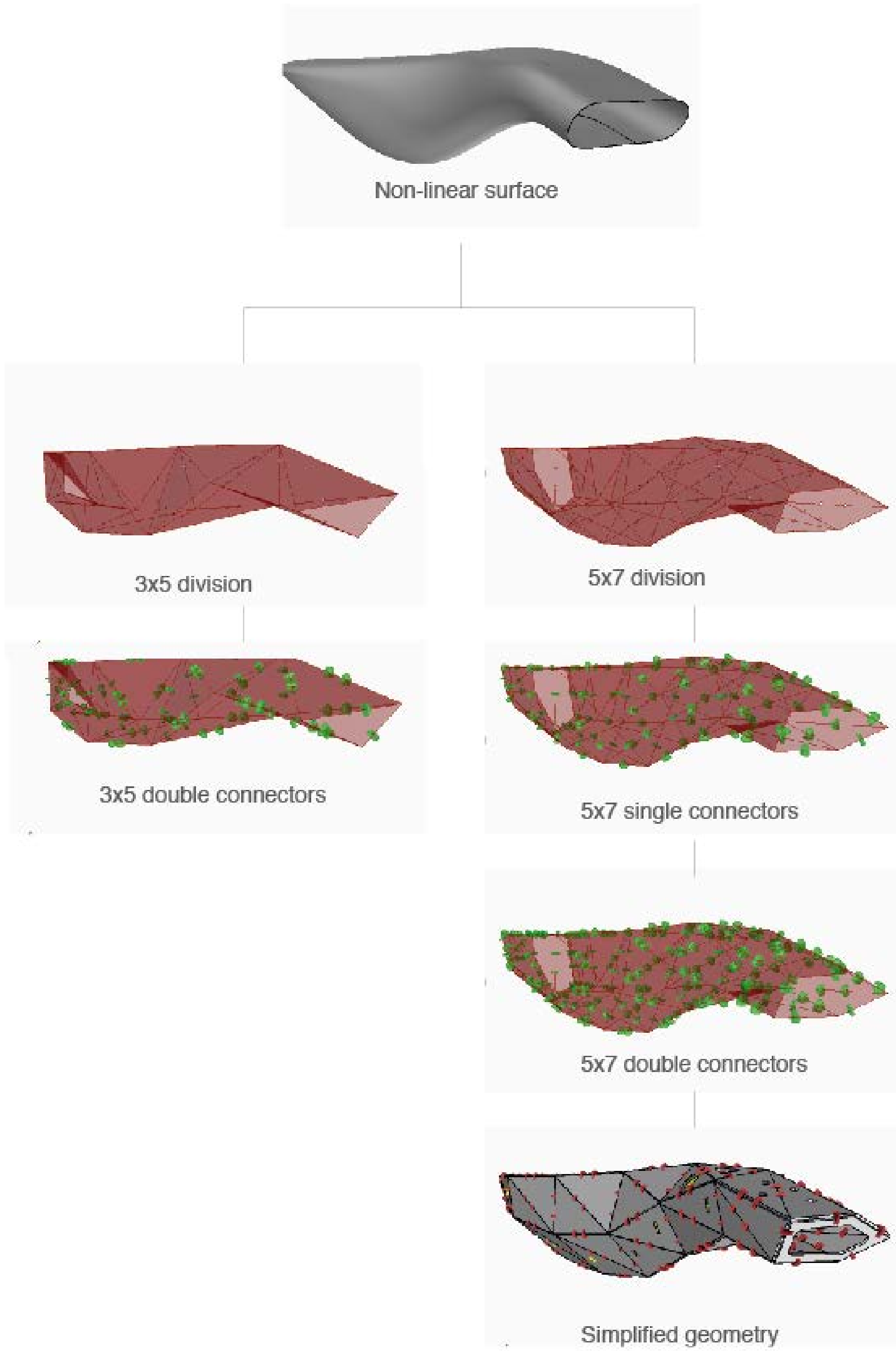



Figure A.1.2 Simplified geometry from non-linear surface

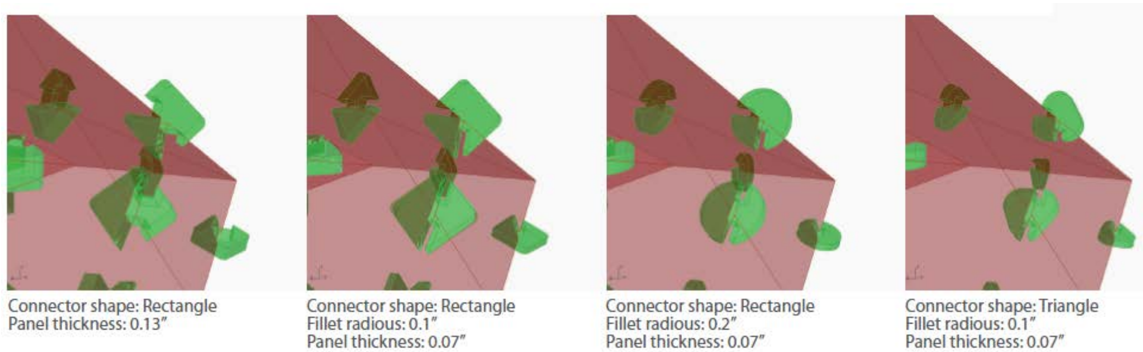



Figure A.1.3 Notches on connectors and surface pieces that put in each other

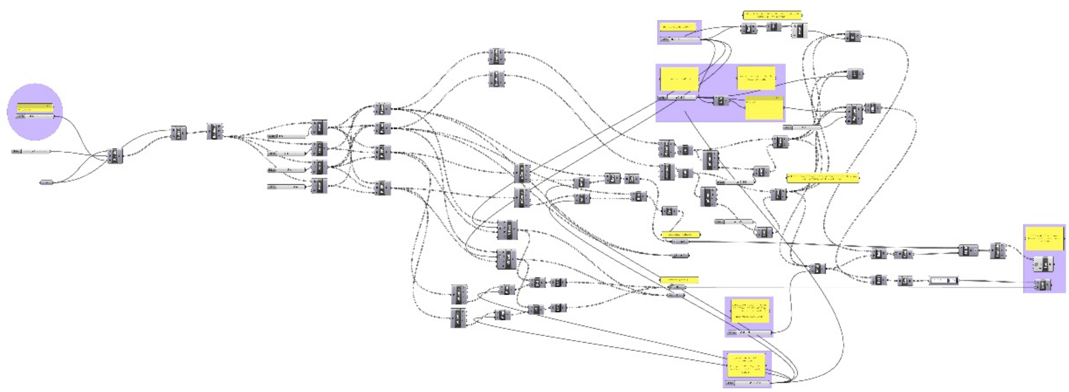


Figure A.1.4 Rhino Grasshopper definition

The diagram and photo below represent planar figures of the ukulele body, connector, fret board, and inner structural frame (figure A.1.5).

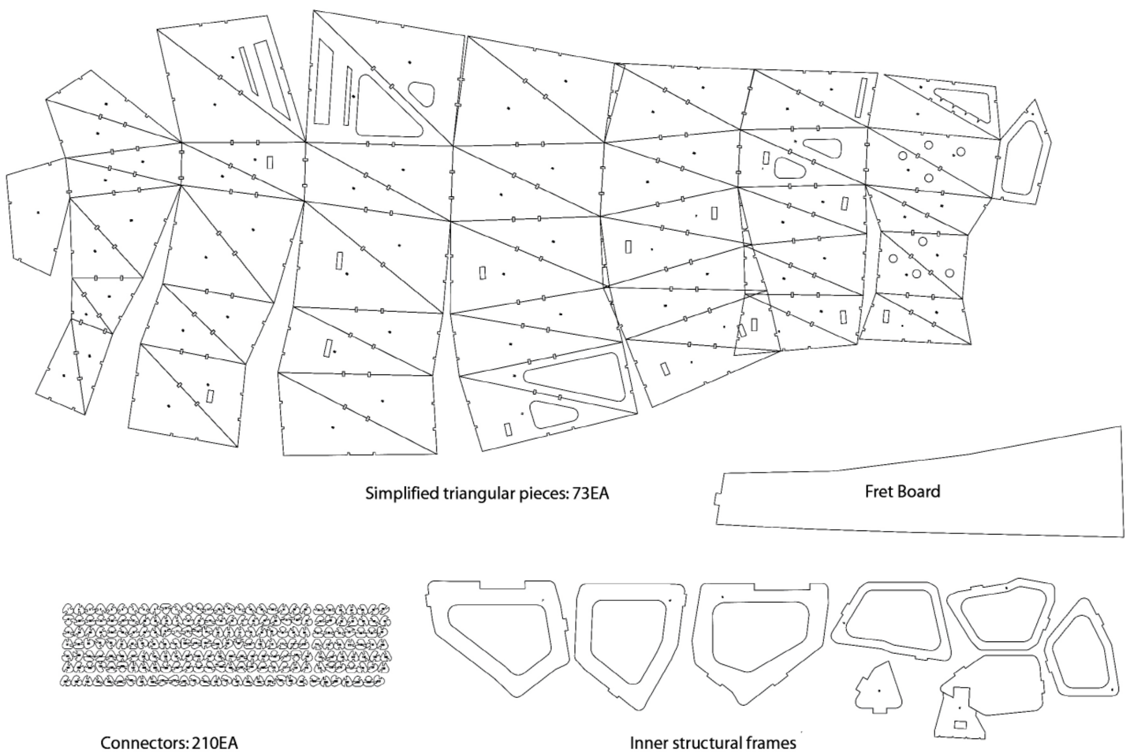



Figure A.1.5 Planar figures of tessellation tectonics

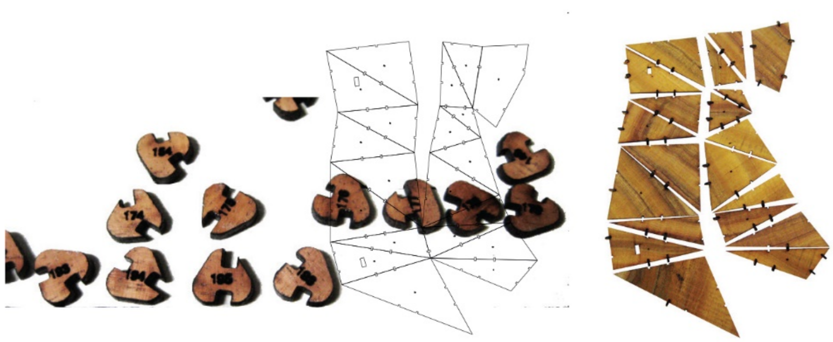


Figure A.1.6 Planar figure model

The photos below show the assembly process and how the connectors are held between two pieces set at different angles and how inner structural frames are inserted in the surface piece (figure A.1.7). As a material, I utilized first grade Hawaiian Koa wood as used in the construction of the original Hawaiian ukulele to emphasize the abstraction by comparing the original one to this.


Figure A.1.7 Assembly process

I made a fret board and bridge using CNC router by cutting three-dimensional geometry which reflects the curved form of the ukulele body surface. (figure A.1.8).

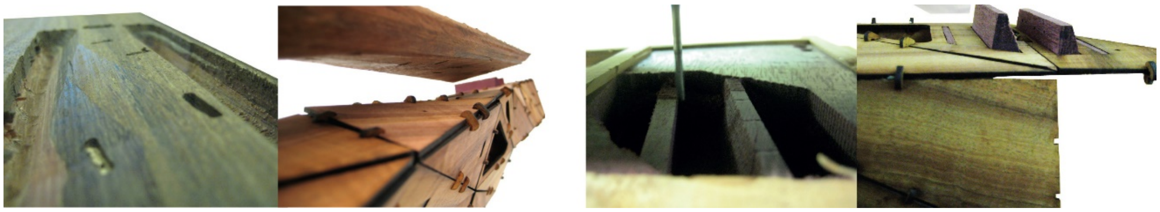


Figure A.1.8 CNC cut of fret board and bridge

Figure A.1.9 Reinterpreted ukulele using tessellation tectonics (above) and original Hawaiian ukulele (below right)

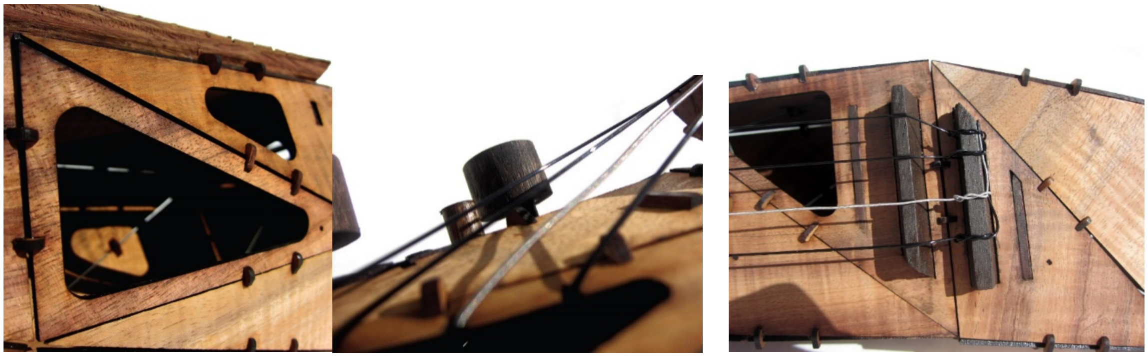


Figure A.1.10 Reinterpreted ukulele details

## A.2 Conclusion

The experiment is meaningful in that it represents a possibility to utilize tessellation tectonics in the reinterpreting Hawaiian identity through the interpretation of wave and Koa material. The experiment also contributes to the academic and professional worlds' usage of digital fabrication by encouraging consideration of the construction of non-linear form geometry and the relative appropriation of cost, time, and workability.

Figure A.2 Playing parametric Ukulele at the Waikiki beach

# Appendix B: 3D Voronoi Cell with Structural Frames: Assembly Logistics for Structural Frames of Voronoi Cell Using Folding Tectonics

## B.1 Fabrication of 3D Voronoi Cell by Folding and Assembling Each Structural Frame

3D Voronoi Structure has following process (figure B.1). In this experiment, I make a cell in the middle of 3D Voronoi units. The goal of this experiment is to apply the idea into the construction scale by folding and assembling segments of structural frame: a) I defined a simple box-shaped object in Rhino 3D software as the first step of fabrication of 3D Voronoi structure. b) Then, I inserted points inside of the box. According to the locations of the points, the geometry of Voronoi structure is defined. Thus, it is critical to design the locations of points in the real project. In this experiment, however, I do not imbue any particular meaning at the locations of points. c) I applied the command of "3D Voronoi" in Rhino to form 3D Voronoi structure from the distributed points. d) The box-shaped geometry is divided three-dimensional Voronoi solid pieces. e) I applied Rhino Grasshopper script that makes 3D Voronoi structural frame from the Voronoi solid piece. f) Three-dimensional Voronoi structural framing system is created by applying the Rhino Grasshopper script to the Voronoi solid pieces. g) I make an assembly logistics of the cell structure by folding aluminum plate.

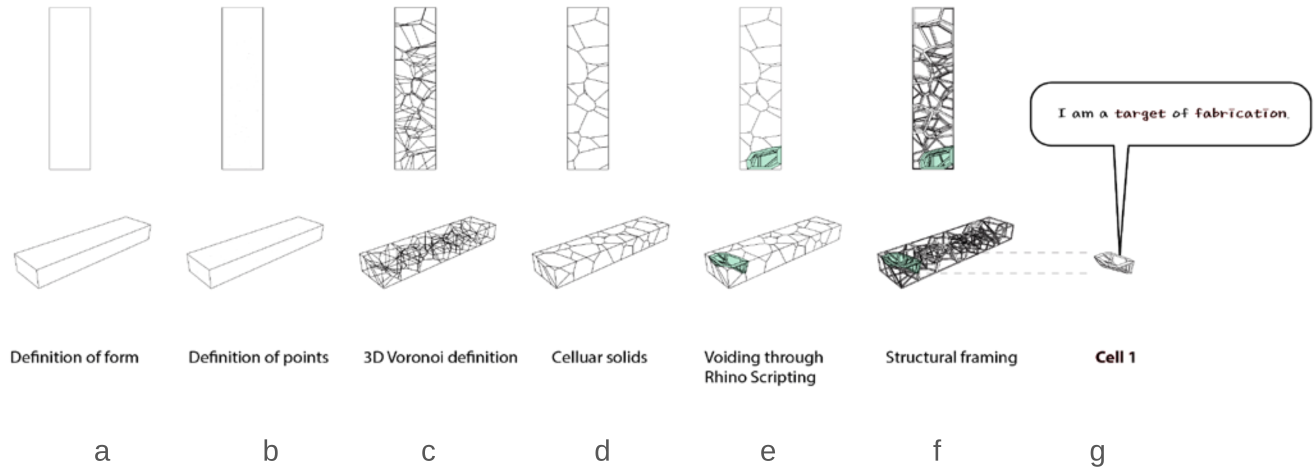



Figure B.1 3D Voronoi structure

The assembly logistics as a planar figure is represented in the diagram below (figure B.2). Layered aluminum plates are three-dimensionally overlapped and jointed together.

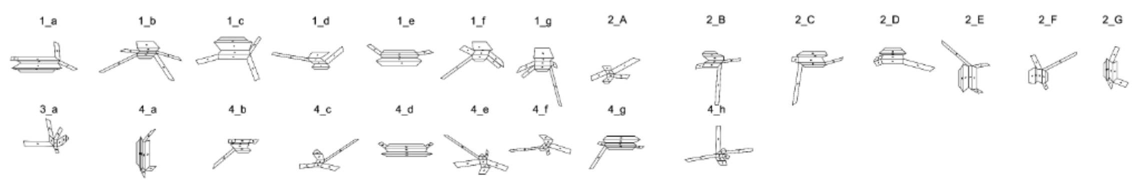



Figure B.2 Planar figures through folding tectonics

The laser cut layout of aluminum plate is described in the diagram below (figure B.3).

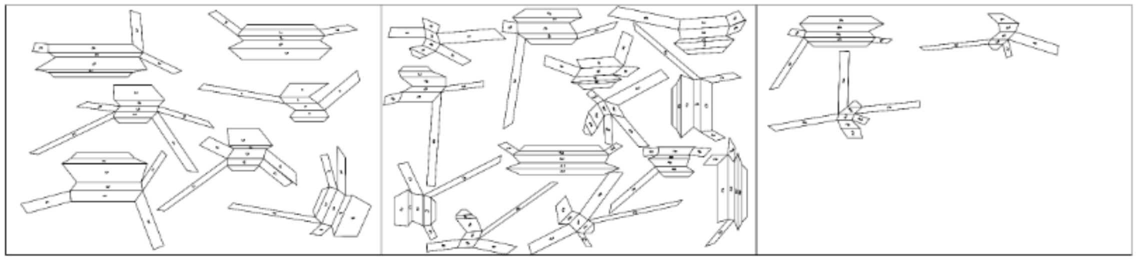


Figure B.3 Laser cut layout of aluminum plate

The diagram below represents how the laser cut pieces are assembled (Figure B.4) into a structural frame.

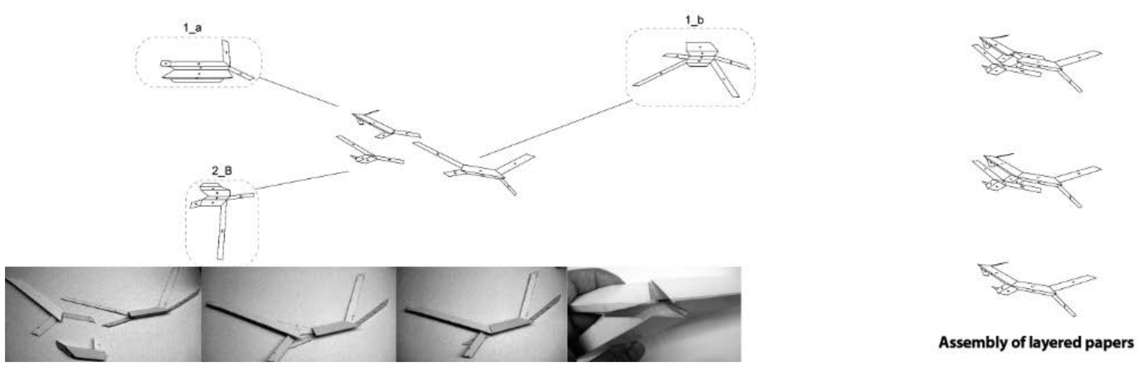



Figure B.4 Connection to layered aluminum plate

The diagram below describes the Rhino Grasshopper script that generates the 3D Voronoi structural frame from the Voronoi solid piece (figure B.5)

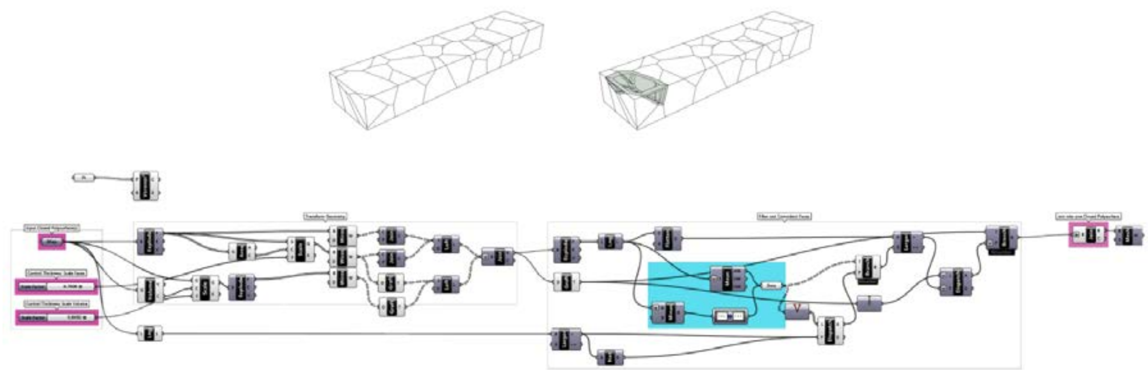
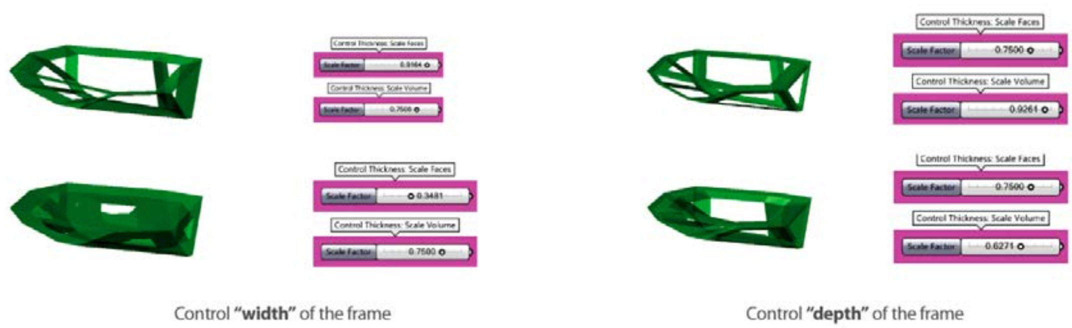


Figure B.5 Voiding through Rhino Grasshopper script

The 3D Voronoi structural frame's width and depth can be easily edited by digital parameters (figure B.6).




Structural frame's width Structural frame's depth

Figure B.6 Parametric data of structural frame

The photos below show the modeling process. The experiment is done using a thick paper instead of aluminum plates as a study model (figure B.7 and B.8).

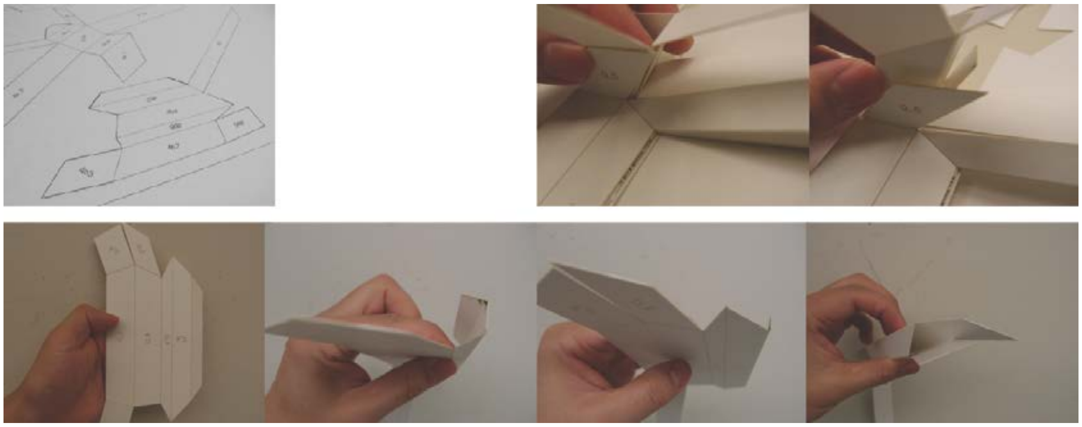


Figure B.7 Fabrication process

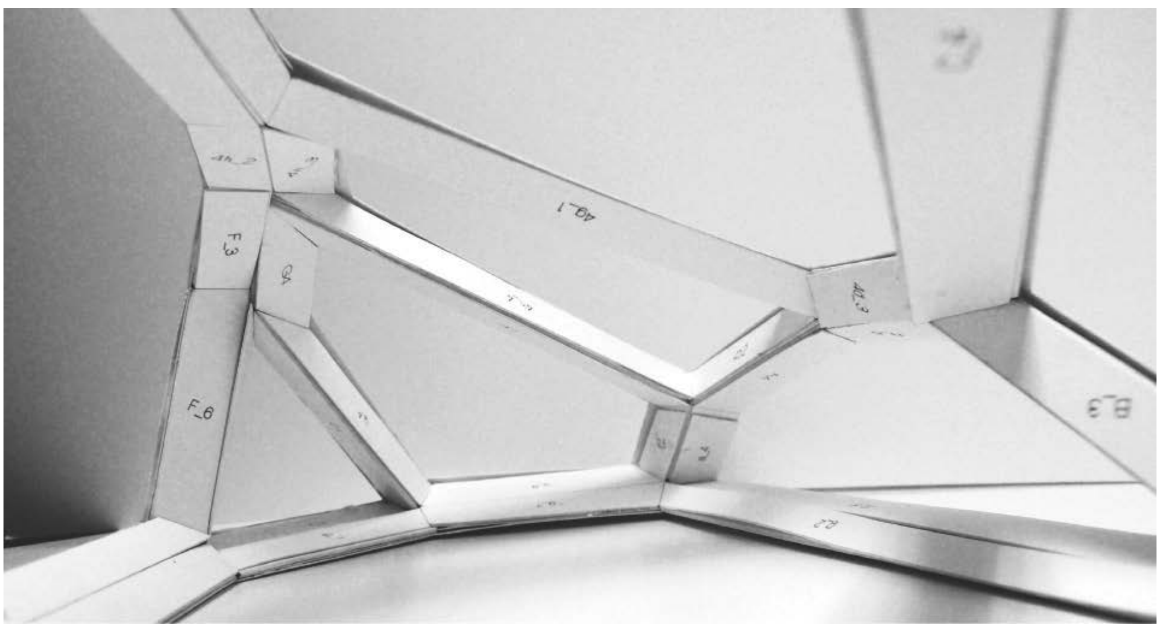



Figure B.8 3D Voronoi cell by assembling structural frames

Below, the image represents a space that is composed of 3D Voronoi structural frames illustrating the potential of its application to architecture (figure B.9).

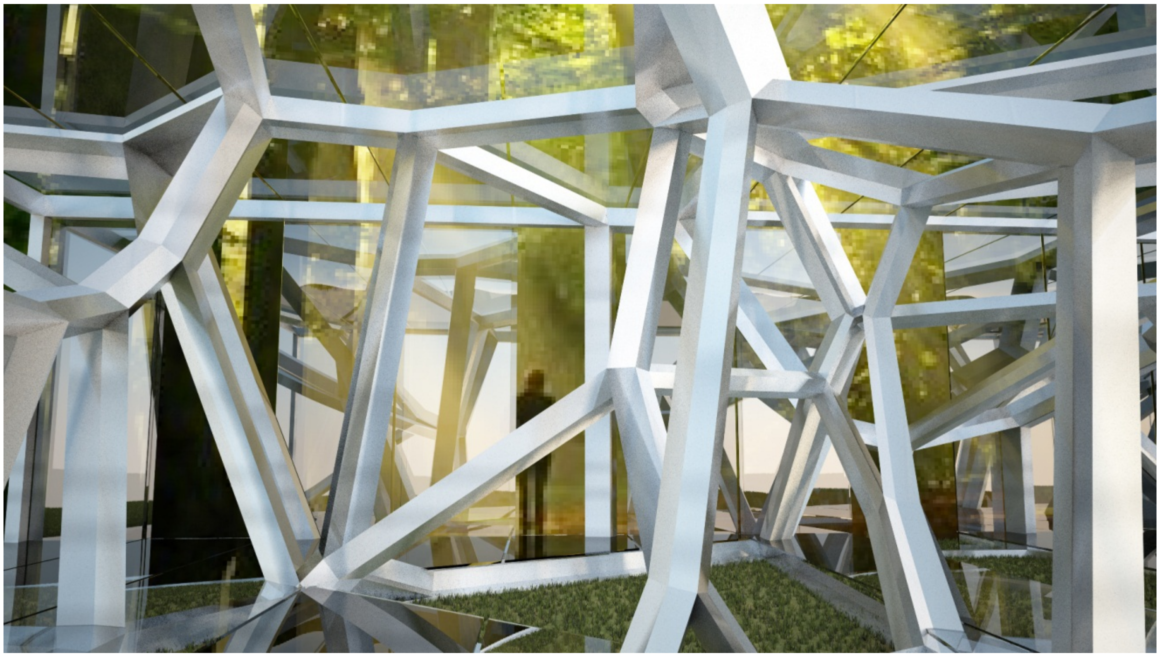


Figure B.9 Rendering that describes the application of 3D Voronoi structure to architecture

## B.2 Conclusion

This experiment has the potential to utilize folding tectonics to fabricate structural frames of 3D Voronoi cell as an architectural scale by reducing workability, cost, and time in the complex geometry thereof. The large scaled steel plate, for example, can be produced at a factory in China, then can be moved to the construction site.